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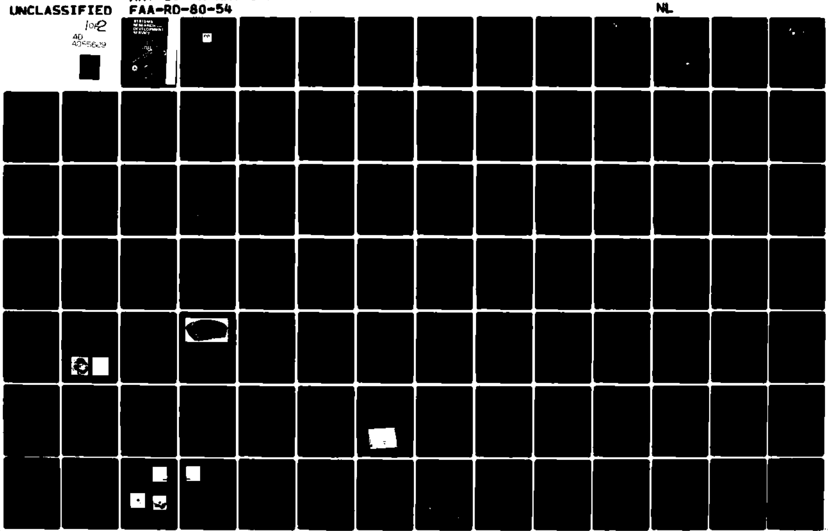
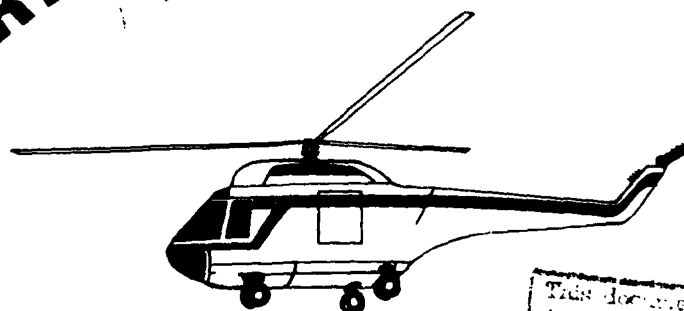


SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

(11)

LEVEL II

REPORT OF R&D ACTIVITY
MAY 1980



U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
Washington, D.C. 20590

It's my pleasure to present this compilation of technical papers authored by various staff members of the Systems Research and Development Service.

This second edition presents 26 papers on selected topics of major research and development efforts in four divisions: Air Traffic Control Automation; Communications and Surveillance; Navigation and Landing; and Systems Development.

Our purpose in publishing this report is to inform the aviation public of the R&D activity in progress at the Federal Aviation Administration. This document is intended to be both responsive to problems experienced in today's operation and to our perception of future conditions.

Robert W. Wedan

ROBERT W. WEDAN
Director, Systems Research and Development Service, ARD-1

Technical Report Documentation Page

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16. Abstract

The 26 technical papers contained in this document provide the details of selected topics of major research and development efforts being undertaken by the Systems Research and Development Service of the Federal Aviation Administration. Emphasis is placed on recent achievements and of expected results in the near future.

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METRIC CONVERSION FACTORS

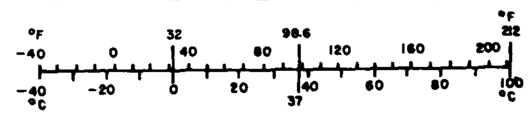
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



TERMINAL INFORMATION PROCESSING SYSTEM

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BIOGRAPHY

Nathan Aronson is the Chief, System Analysis Section in the Terminal Branch, part of the Air Traffic Control Automation Division. He received his BS in Electronic Engineering in 1957 from Polythechnic Institute of New York and his M.S. in Transportation in 1973 from the University of California, Berkeley. Mr. Aronson has contributed to the development of terminal automation programs. In addition, he served in the Office of Aviation Policy where he conducted economic analysis of major FAA development programs. Prior to coming to the FAA in 1959, Mr. Aronson was a radar design engineer in private industry for two years.

ABSTRACT

This paper presents a technical overview of the development program for the Terminal Information Processing System (TIPS). The objective of the program is to provide an electronic data display system that will improve the flight data handling capabilities at ARTS III terminal facilities. It is intended to replace the Flight Data Entry and Printout (FDEP) equipment and the associated paper flight progress strips used in the tower cab and TRACON.

BACKGROUND

The present Flight Data Entry and Printout (FDEP) equipment system at ARTS III facilities has basic capacity limitations which effect the availability and timeliness of flight data, especially in the more active terminals. Because it is a mechanical device, the FDEP equipment is also the source of considerable maintenance problems.

An engineering requirement was prepared for a replacement system which would utilize electronic processing and display techniques. The design objectives are to greatly improve the speed, efficiency, reliability and usability with which flight data can be distributed and manipulated by controllers in the TRACONS and tower cabs. The design objectives also include the electronic integration of the flight data process with other automation aspects of the National Airspace System (NAS).

The Engineering Requirement provided the basis for a competitive procurement to develop an engineering model of a TIPS system. In April 1979, the contract was awarded to Lockheed Electronics Company, Inc., Plainfield, New Jersey. The major subcontractor is Magnavox Government and Industrial Electronics Co., Ft. Wayne, Indiana.

TECHNICAL DESCRIPTION

TIPS will include those functions currently performed by the FDEP subsystem. As previously indicated, the FDEP has operational and system design limitations that affect system capacity and controller workloads within the terminal area. TIPS is intended to remove these limitations and provide an improved terminal capability for entering, displaying, and distributing flight and other non-radar data.

A primary objective of TIPS is to improve the availability and timeliness of flight data presentations to TRACON and Tower controllers. Currently, flight data from FDEP is available only for Instrument Flight Rule (IFR) flights, and may be delayed due to the FDEP's low data communications speed (100 words per minute). In addition, the ARTS computer contains only abbreviated flight data on IFR flights. With TIPS, full flight plan data can be displayed on the TIPS displays for all IFR and Visual Flight Rules (VFR) flights as soon as the information is entered into the terminal computer data base.

A second objective of TIPS is to reduce the controller coordination workload. With FDEP, flight strips are marked and distributed by the TRACON and tower controllers. Also, voice coordination is routinely required between the tower and TRACON at the time flight responsibility is transferred. With TIPS, a simple computer entry action will suffice to transfer flight and control information between tower controllers or between the tower and TRACON, or between towers.

A third objective of TIPS is to support the increased demand for VFR flight services. At present, several controllers may request the same basic flight information from a VFR pilot. With TIPS, this flight information can be initially entered into the terminal data base and thereby made available to all TRACON and tower controllers to assist them in providing VFR flight services.

The major operational capabilities provided by TIPS are:

a. Tower Electronic Tabular Display Presentations. Tabular displays are provided at the tower operational positions and will contain selected flight, weather and status information which is of current interest to the controller. The displays will also present full flight plan information in response to a controller request.

b. Improved TRACON Flight Data. The existing ARTS Plan Views Displays (PVDs) will be used to display summary flight data for all active flights (i.e., those which have a Full Data Block (FDB) displayed) and inactive flights (i.e., those on the Arrival/Departure or Coast/Suspend List). Summary flight data is displayed by using the "alternate data switch" capability which causes flight data to temporarily replace tracking data on the PVD. In addition, summary flight data presentations for current and expected flights are presented on new tabular displays for planning purposes.

c. Enhanced Local Flight Data Entry. Local flight data will be entered into the computer data base for presentation on terminal displays. A controller will be able to enter VFR and local IFR flight plans, change IFR flights to VFR status, and make other flight data entries which relate to terminal area operations. Once the local flight data is entered into TIPS, it can be displayed at any TRACON or tower controller position which needs the information.

d. Improved Flight and Control Information Transfer. When control of a flight is transferred between the TRACON and a tower, a single controller action will usually provide the receiving position with sufficient flight information to eliminate routine voice coordination. When a flight is transferred from one tower controller to another, a single controller action will replace the physical movement of the flight strip from one controller position to another.

e. Simplified Tower Manning Level Adjustment. In response to increases or decreases in flight activity, controller positions may be combined or decombined by a single supervisory action. When two positions are combined, the information displayed at those two positions will automatically be combined and presented on a single display. When a position is decombined, the information needed at the new position will be automatically presented on the new display, and the information needed at the original position will be retained on its display.

System Design Hardware

The TIPS system is configured into a main processor a Terminal Flight Data Processor (TFDP) and up to six display/processor subsystems which can each service up to 12 display terminals. Each processing function is performed by Lockheed's Advanced Bipolar Processor (ABP) which is a ruggedized and repackaged version of the Super Pace minicomputer built by National Semiconductor. The ABP operates on a universal bus structure that is easily adaptable to redundant, parallel, or multi-computer configurations. All input and outputs are memory-mapped. Therefore, input/output devices are serviced as another memory location, and any memory reference instructions can be executed at the selected input output post. The computer operates on a 300-micro-second micro-cycle with an average instruction execution time of 1.2 micro-seconds. The hardware configuration for the TIPS system is shown in Figure 1.

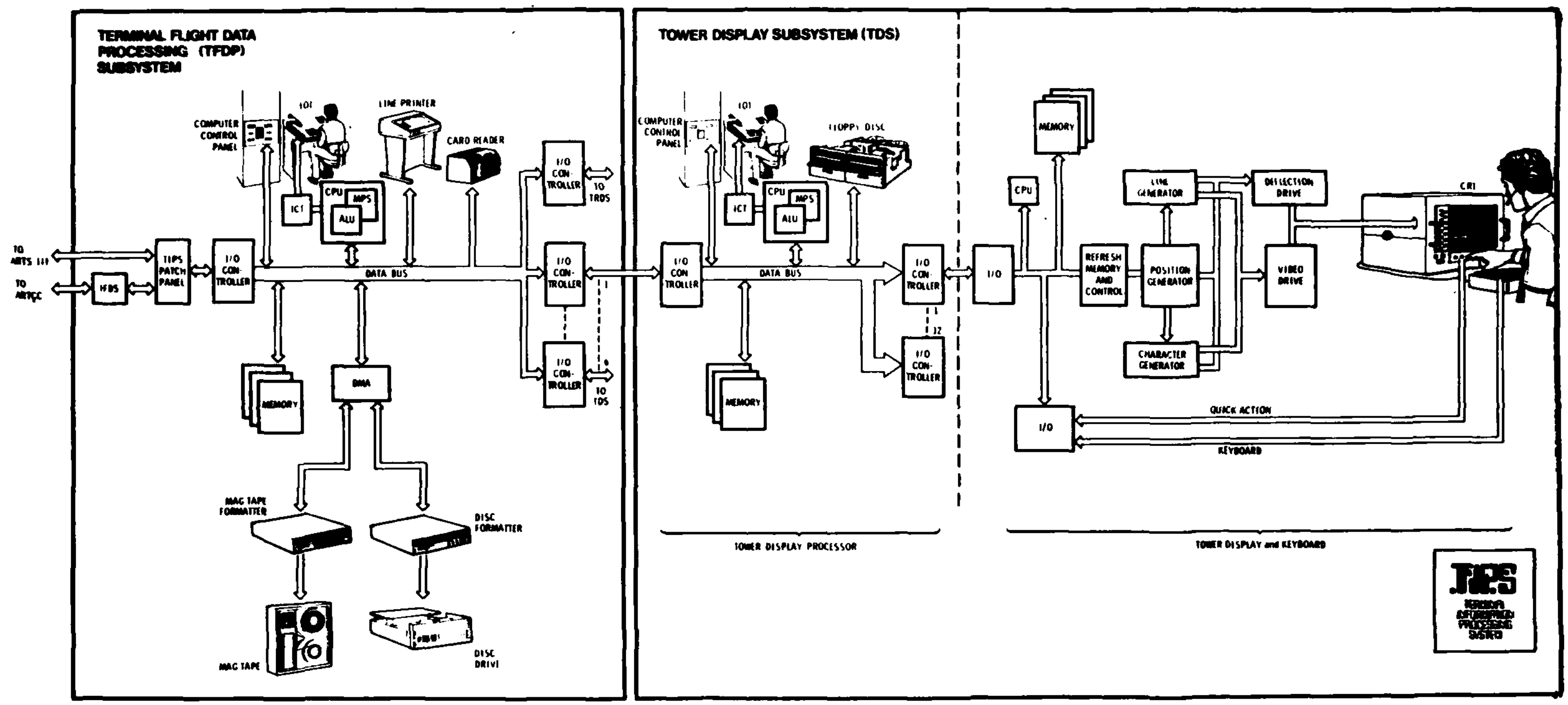

Figure 1. TIPS Hardware Function Diagram

Within each processor subsystem, functional and hardware commonalities exist, in that, memory Central Processing Unit (CPU) and input output devices are configured identically and thus interchangeable through printed circuit board replacement. Display deflection and video processing circuitry is also configured for printed circuit board interchangeability.

The simple addition (or deletion) of memory and input output devices provides flexibility and permits adaptation to individual terminals.

Use of the universal bus structure also permits flexibility in the use of peripheral devices.

As shown in Figure 1, the main processor TFDP contains the disc drive unit interfaced to the data bus through the disc formatter and the Direct Memory Access (DMA). The disc contains the operational programs, main data base, diagnostics, and debug programs which are accessed by the resident software. The Magnetic Tape Unit (MTU) and its magnetic tape formatter also interface with the data bus through the DMA.

Control of CPU operations is provided by the Input Output Terminal (IOT) with additional control monitoring and program modification provided by the computer control panel. A key lock is provided on each control panel to prevent inadvertent or uncontrolled use.

Modified or new program source cards may be entered into the data bus through the card reader. Source and object program listings in addition to error messages or maintenance information are printed out by the line printer.

Flight data enters TIPS through the patch panel from ARTS III directly and from ARTCC through the Inter Facility Data Set (IFDS). This data is bufferered and assembled in the input output buffer and block transferred to memory by the CPU. The message data is processed and stored in memory or is transferred to the main data base located on disc.

Up to 65k words of memory (16 bits plus parity) can be directly accessed by the CPU. Additional address flag bits are available to indirectly access up to three additional banks of 65k words of memory each for a total memory capacity of 256k. All memory is static Random Access Memory (RAM), with data retention provided during power loss by a backup battery supply.

In each processor subsystem (TRDP and TDP), a local data base of 50 flight plans is maintained in random access memory in the event that the TFDP, CPU, memory, or input output fails. In this event, operation is continued with minimal loss of operational capability. The system self restores all data bases and processes all pending messages when full service is restored.

The memory capacity of the TDP is identical to that of the TFDP and is expandable in blocks of 8k words.

The TRACON and tower cab displays are physically identical and provide for presentation of selected information stored in the TIPS data base. See Figure 2, Display Terminal Configuration. The displays are under control of the display CPU which performs Cathode Ray Tube (CRT) screen update from messages generated by the TDP. Operator data entry devices include an ARTS III type keyboard, quick-action pressure-sensitive actuators located on the CRT's periphery and a remote hand-held control unit for local and ground control positions. These devices enable the operator to request new display data and to modify displayed data. The CPU receives data entry requests through the Input/Output (I/O) buffer, which contains universal 8-bit parallel ports that connect to the universal data bus. The CPU Loads the refresh memory with appropriate formatted data, and the refresh memory control performs independent display screen refresh.

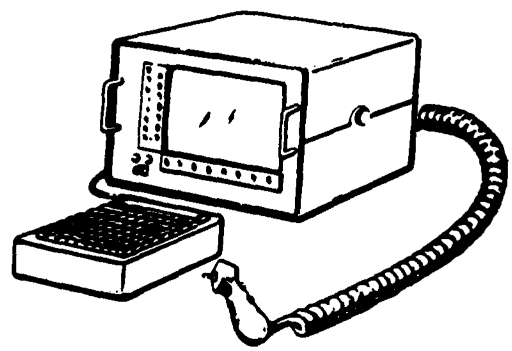

Figure 2. Display Terminal Configuration

The display incorporates a random-positioning, stroke-generated character writing and constant-velocity x-y line generation capability. Figure 3 is a block diagram of the display terminal. The terminal contains:

- TDP communications
- Microprocessor
- I/O interface
- Refresh memory control
- Position generator.
- Stroke-character generator

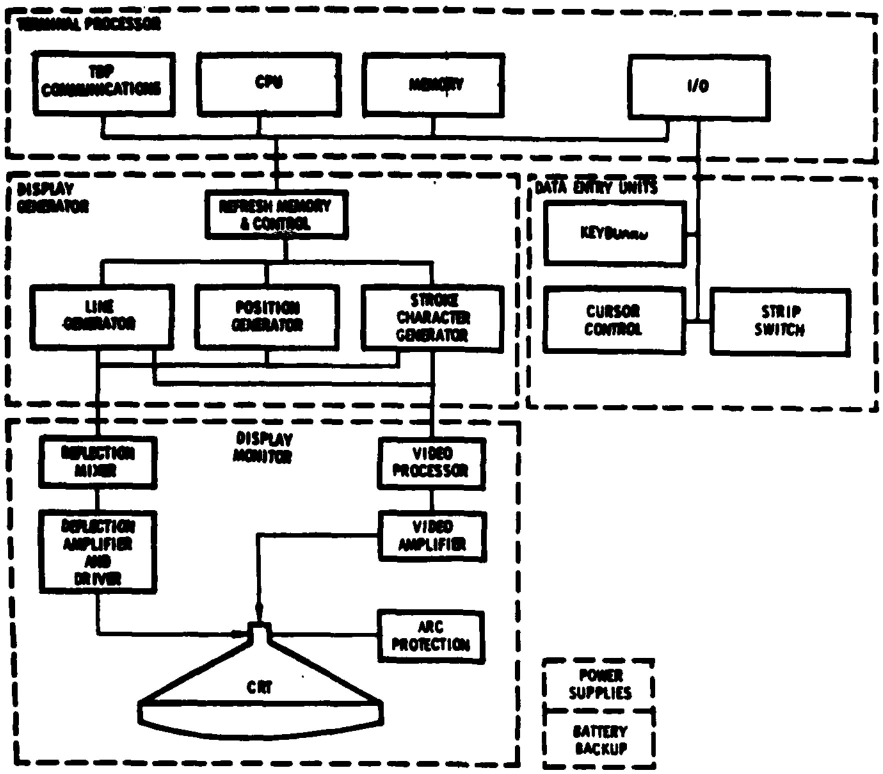

Figure 3. Display Terminal Block Diagram

- Constant-velocity line generator
- Deflection drivers
- Video amplifier
- 15-inch (diagonal) CRT (P31 phosphor)

This design was chosen to provide:

- High legibility display
- High brightness and contrast
- Versatility
- Ease of implementation for functional and capacity growth
- Ease of maintenance

To enhance the contrast, the CRT uses a spectral filter matched to the P31 phosphor, which has a 55-percent peak transmissivity. The front surface of the CRT is etched and coated with an antireflective coating to minimize reflections.

A complete quick-action capability is being provided for each display by using pressure-sensitive switches mounted on the bezel adjacent to the left side and bottom of the display face to address horizontal lines and vertical data columns, respectively. The switches are associated with the CRT's computer-generated legends by leaders. This provides each controller with an easy, accurate, and flexible method of identifying and acting upon specific displayed information.

The hand-held control unit provides local and ground controllers with a means to quickly and easily transfer data from the top of the arrival or departure lists, to the controller who normally assumes responsibility for the aircraft, without looking at the display. The unit also provides the functional capability to address data on the display by using a four-way cursor control switch. The control unit and the pressure-sensitive switches have identical addressing capabilities.

An ARTS III type keyboard provides full data entry and editing capabilities and is adapted to the TIPS functions and symbology.

Software Description

The functional organizations and software module interrelationships of the TIPS computer programs are shown in Figure 4. The block diagram on the left side of the figure applies to the TFDP functional organization and software module interrelationships. The block diagram on the right side of the figure applies to the functional organization and module

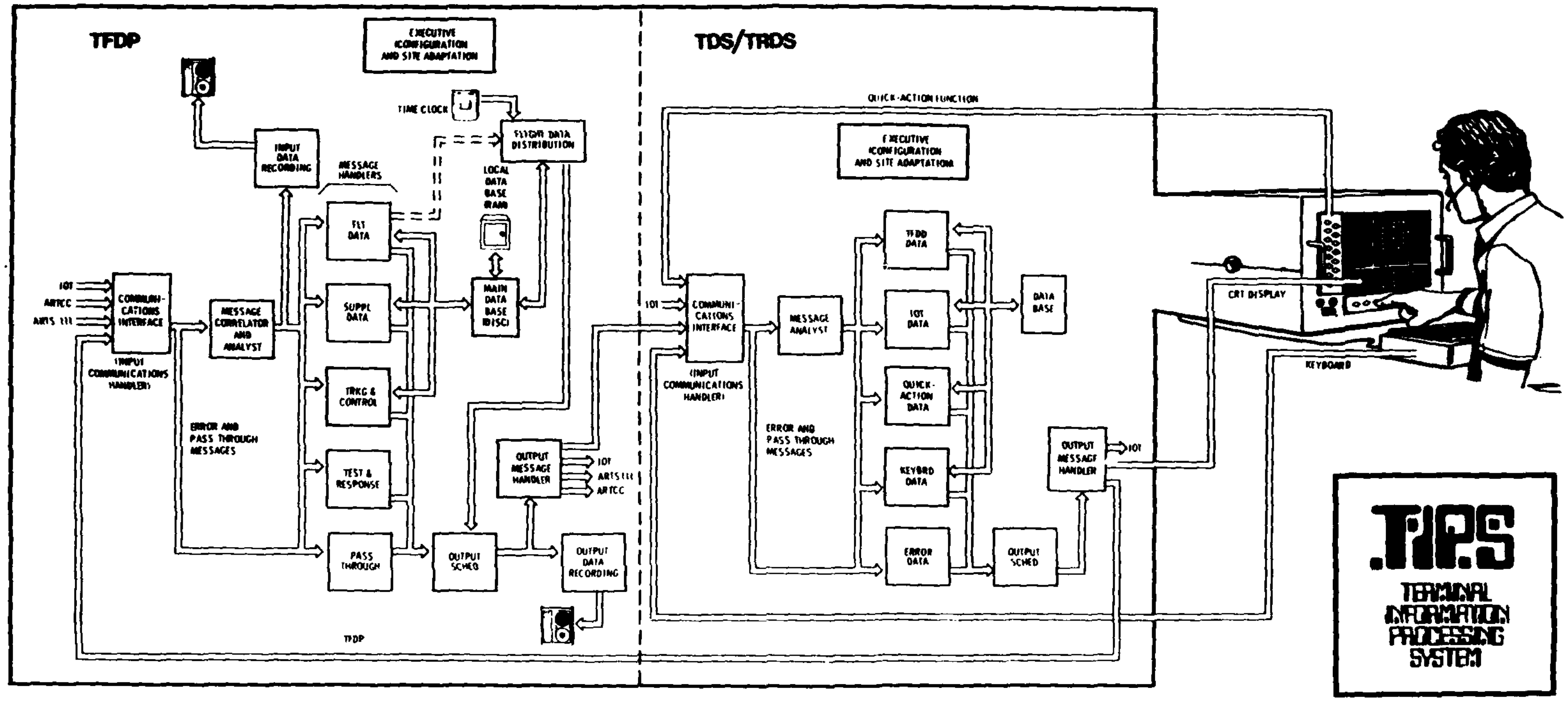

Figure 4. TIPS Software Functional Diagram

interrelationships within either the processor subsystems TDS or TRDS program because of the great similarity between the TDS and TRDS programs. All display format and reconfiguration data is transmitted from the TDP and TRDP to each display terminal. No functional message processing is performed in the display terminal and all intelligence is contained in firmware.

In each program, the input communications handler module verifies message parity, the Longitudinal Redundancy Character (LRC), and the start and end of test protocol. If an error is detected, the message is immediately routed through the message handler module to the program output. Messages passing input verification are routed to the message correlator and analyst for identification and for additional format-field and test-error checking. Messages successfully passing these checks are placed in processing queues, time tagged, and recorded. They are also routed to the message handler modules. Message processing functions, though different in the processors, are all separate and independent modules. As such, they can be easily linked or combined in any processor to form site-adaptive configurations.

Each of the five message handler modules processes a different message class. Certain processed messages are stored in the main data base. The overall data base consists of the local data base and the main data base. The local data base stores images of active data and a central flight status table in Random Access Memory (RAM). The main data base contains all flight plan data stored on disc. Other processed messages are outputted from the program via the output scheduler and output message handler. The output scheduler queues the messages on a priority basis, while the output message handler distributes the messages to the destination devices as the destination devices become available to receive the data. Output messages are recorded as they pass from the output scheduler to the output message handler. The output message handler also appends special characters such as start of text, end of text, and LRC to each message. The output message handler includes a pending message table where the message remains available until it is accepted completely by the destination device.

Configuration and site-adaptation tables are controlled and accessed by the executive.

Timed flight data distribution is handled by a separate processing module. This module accesses the data base for solicited and unsolicited data updates and flight plan presentations. The function is based on adaptive data created by the ARTCC, or locally; and its output identifies a Unit Message Buffer (UMB) for transmission to a display terminal.

Controller actions are encoded by logic in the display and are transmitted as messages to the TDP or TRDP communications interface. When the keyboard or quick-action message is validated, and acknowledged, the interface task transfers it to the analyst task, which subsequently routes it to the appropriate processing task. The processing task can either reference the local data base or initiate a TFDP message. A display message is immediately transmitted when local action is sufficient. The display output follows a TFDP reply when the controller action requires communication to the TFDP.

The TDP and TRDP also receive unsolicited TFDP messages that are not replies to controller actions. These messages modify the TDP or TRDP data base and can result in new or modified display information.

Internal queues are maintained in priority order for the efficient use of resources. The average length of all queues is less than one message, but the queues are still necessary to handle message bursts in a rapid and orderly manner. The program structure of independent tasks and queues is well-suited for TIPS message processing.

The parallel tasks must, in actuality, be performed with a processor that provides service to only one task at a time. This is accomplished by allowing input output functions to proceed without processor intervention, and with a task scheduler (executive) that executes tasks sequentially in priority order. The logical message flow is independent of the scheduler because there is a surplus of processor time under all message load conditions. Individual tasks are queued and completed in priority order.

Failure Modes of Operation

Because of the high reliance on flight data information, limited operation is designed into the system in the event of failure of elements in the flight data network. If one of the tower displays or one of the TRACON TIPS displays fail, then by combining display functions, operations can continue until the failed display is replaced or repaired. A typical example would be if the local control position display failed. Either local control and ground control could be combined or the clearance delivery/flight data display could be combined and the available display could be taken over by the local control position and operation would continue after only a few seconds of changeover. Similarly this also applies to the TRACON.

If the tower display subsystem processor should fail than associated displays are designed to recognize the failure and retain the data on the displays. The most critical position is local control and this display will have an arrival and departure list of both active and pending flights which contains twelve aircraft and other needed data.

Therefore, the local controller can continue operations by partial use of the display data list and with the aid of a pad. If the failure is anticipated to continue beyond several minutes, then the flight data personnel will backup the operation by preparing flight strips manually until such time as the processor becomes available.

A failure of the major TIPS Processor (TFDP) will not stop the tower or TRACON processor operation, since both subsystem processors contain a flight data base for 60 arrival, 60 departures IFR flights and 50 local operations. This allows the facility to operate typically for 30 to 60 minutes until the TFDP will be brought back on line. Again, manual operations can backup prolonged outages. Redundant TFDP and communication channel for large facilities can reduce the probability of this occurrence to almost zero.

If communication to the ARTCC should fail or if the ARTCC itself should fail, the TFDP data base will allow a continued but limited operation of the complete terminal area (similar to TFDP failure) until such time as the malfunction is corrected. Storage of 1,000 flight plans is available in the TFDP. Manual keyboard entry of flight data messages for distribution to TIPS displays will also be possible in the event of interfacility data line failure.

TIPS Interface

The TIPS equipment is being designed to interface with and process flight data information between the center computer and the ARTS III equipment. TIPS related changes in the ARTS equipment will permit (a) the presentation of flight plan data to Radar Controllers (on their ARTS displays), (b) the ARTS III keyboard to handle all FDEP type messages, (c) the common handling of flight plans entered either from the ARTCC, TIPS or local entry devices and (d) the entry of beacon code assignments for VFR and local IFR flights. The en route ARTCC computer program changes required for the prototype TIPS include those needed to: provide full flight plans to TIPS (and ARTS), interface the ARTCC computer with the TFDP, and to provide the ability to handle all FDEP type messages over the medium speed (2400 bps) interface. A data communications capability is required which permits the ATC system to operate in either a TIPS or a non-TIPS mode. When operating in a TIPS mode, the TFDP will interface with the ARTCC and ARTS computers via a patch panel. When the ATC system is operating in a non-TIPS mode, the ARTCC and ARTS computers will communicate via the patch panel without involving the TFDP. The existing ARTS-NAS interface will be used for the TIPS mode.

TIPS system interface engineering and operational testing for the prototype development systems will take place at both the National Aviation Facilities Experimental Center (NAFEC), and at an operational ARTS-III field facility. The field facility testing will essentially be performed in the ARTS III facilities tower cab, and an associated satellite tower cab. The object of these tests will be to demonstrate the electronic flow of flight data in the tower cab; the man-machine interface in a live environment and the use of display equipment in the tower cab. The field test system will have a dedicated medium speed interface with the ARTCC, but only a partial data interface. There will be no ARTS interface connection for the field system. At NAFEC all field interface and operational evaluations will be pre-tested; in addition, a full TIPS/ARTS/ARTCC interface will be evaluated with emphasis on the TRACON/Tower Cab flight data flow.

Summary of Program Status

The TIPS program has been planned to replace the FDEP equipment and paper flight strips with a contemporary electronic processing and display system. A contract for the development of prototype equipment has been awarded to Lockheed Electronics Company Inc., in April 1979. Prototype system testing is scheduled to begin at NAFEC in August 1980, and at a field site in February of 1981. The comprehensive test and evaluation program for NAFEC and the field site will be concluded in September of 1981. Based upon the knowledge obtained through the development program and the test results, a Technical Data Package (TDP) is schedule to be submitted by January 1982 to FAA's operational services for their use in a TIPS implementation program.

References

1 Terminal Information Processing System (TIPS) Engineering Requirement, FAA-ER-D-120-006.

BASIC METERING AND SPACING FOR ARTS III

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Biography

Gary Rowland, BSEE, University of Maryland, 1970 is a member of Etta Kappa Nu. He has been employed by the Federal Aviation Administration for nine years, involved in terminal automation development efforts. Formerly Program Manager for Terminal Conflict Alert, he has served in the equivalent role for the Terminal Metering and Spacing program for the past year.

ABSTRACT

Basic Metering and Spacing is a development program designed to take the first major step towards automation of a complex air traffic control function: that of metering, sequencing, scheduling and spacing terminal arrival aircraft. The design of the program and its current status is described along with potential benefits, testing results and future plans. In addition, a brief description of some of the complex issues which are yet to be resolved, is provided.

Introduction

In 1974, FAA awarded the basic Metering and Spacing (M&S) ARTS-III development contract to Sperry UNIVAC. The contract required development of M&S software, integrated with the ARTS-III operational program, for use in a thorough engineering and operational evaluation of the M&S concept.

The basic M&S software is now undergoing test and evaluation at NAFEC. The software is integrated with a Denver, Colorado operational ARTS-III program which includes Conflict Alert (CA), (see Figure 1 for hardware configuration). The test objectives are to obtain M&S performance measures in a high demand, realistic simulation environment including:

a. Sensitivity of M&S program to errors in wind estimation and response to changes in terminal area winds.

b. Compatibility of M&S commands with existing procedures and CA logic.

c. Performance variations as a function of M&S control geometries.

A description of the specific performance measures to be used and of the two control geometries to be tested is contained in the following sections:

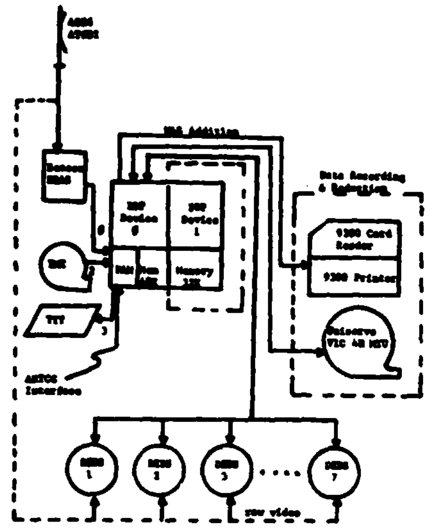

FIGURE 1, ARTS III, M&S EQUIPMENT CONFIGURATION

Functional Description

The primary objective of M&S is to enable an increase in airport capacity without adversely impacting system safety. The increase in system capacity will be achieved by providing more consistent inter-arrival spacing of aircraft, thus assuring an increase in runway utilization. The automated M&S function should also prove beneficial in other areas such as an overall reduction in arrival delays (with associated savings in fuel), the equitable distribution of delays, and the absorption of any necessary delays in the most efficient manner.

In general, the M&S function will: a) control the flow of arrival aircraft into the terminal area, termed Metering: b) determine the landing order based on each aircraft's nominal landing time, using predefined flight paths, termed Sequencing, and c) establish schedule times at various points for each aircraft which will assure proper spacing of aircraft or the final approach course. The M&S logic aids in the control of arrival aircraft by the generation of recommended commands to satisfy the established schedules.

The M&S software system is divided into six major functions directly related to control of arrival aircraft from handoff from En Route control to the runway threshold:

1. Executive Control
2. Command Generation
3. Scheduling
4. Metering
5. Display Output
6. Adaptive Wind

Executive Control - The Executive Control Function is essentially identical to the basic ARTS dual beacon system and provides for control of all other functions on a priority basis in addition to power failure recovery logic.

Command Generation - The command generation module provides four different approach geometries, representing three unique control concepts. The first is a "trombone" approach to runway 26L (Figure 2) in which a fixed (downwind) heading from the inner fix (IF is generated. The second is a TALL (Transition, Approach and Local Landing) approach to 26L which provides a variable (fan) downwind heading from the IF to absorb necessary delay. Only these two geometries are being tested in the current series of tests at NAFEC. The third and fourth geometries provide for profile descents to runway 26L and 17R, respectively. The profile descent (PROD) geometries use a restructured arrival airspace and provide fixed downwind heading from two IF's and fan type headings from the other (remote) IF's. PROD geometries also inhibit the display of sequence area headings (performed by the pilot in accordance with published procedures). In other respects the geometries are comparable, i.e., in each geometry M&S determines a sequence, calculates the delay, if any, and provides the necessary commands to satisfy the established schedules. M&S also performs resequences, when the existing sequence is undesirable or

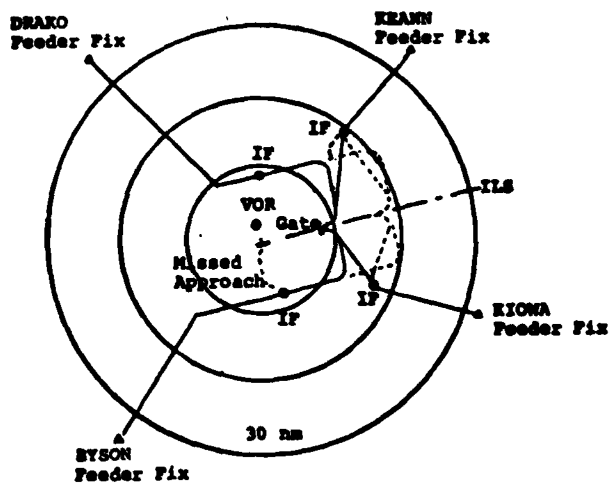

Figure 2. "Trombone" Approach to Runway 26L

unattainable, and issues altitude and speed commands to conform with the desired approach pattern.

Aircraft are automatically placed under M&S control when Flight Plan (FP) data is received which indicates that the aircraft is an arrival to the M&S controlled airport. FP data may be received from the En Route Air Traffic Control or via manual keyboard entry.

Command Generation requires four unique pieces of information. These are:

1. The predefined approach geometry.
2. The aircraft profile data (aircraft characteristics).
3. The aircraft performance measurements.
4. The aircraft schedules.

The approach geometry consists of prestored information (the Geometry File) which specifies all M&S control points and identifies the various approach paths. A unique Geometry File is required for each configuration. The Geometry File approach paths are dependent upon the aircraft performance class and the Feeder Fix (FF).

Two performance classes are defined for M&S: a high performance class for all aircraft capable of maintaining 180 knots indicated airspeed; and a low performance class for all other aircraft. The performance class is predefined, and based on the aircraft type (contained in the flight plan data).

Arrivals use one of four approach gates. Each gate may have one or more feeder fixes. The FP data may identify any one of these fixes for simplicity. The M&S define "logical feeder fixes," each of which (up to 31) will be dedicated to either high or low performance aircraft. Each assigned fix shall have an associated logical feeder fix and each logical feeder fix has an associated set of data defining the unique approach path from that fix.

The approach path for each FF are divided into four segments (Figure 3).

1. The transition area
2. The sequency area
3. The base area
4. The final area

Areas of controllability are normally provided in both the sequence and base areas. Various methods are available to define the approach routes, i.e., control arcs (a distance from a referenced point), limit radials (measured from a referenced point), and/or prestored headings, may be used to specify the approach path.

Profile data is derived from the aircraft type and is used to determine the aircraft's probable speed, rate of descent, and rate of deceleration within each segment of the approach path.

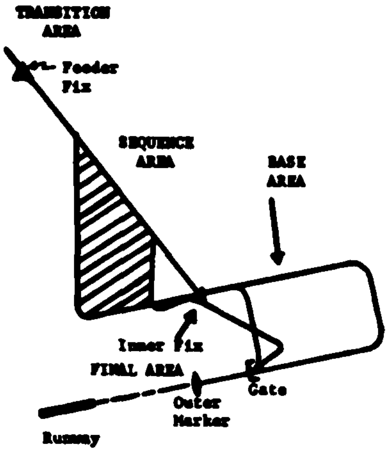

FIGURE 3, SEGMENTS OF THE APPROACH PATTERN

Aircraft performance measures include identification of the current position, speed, heading and altitude, and a calculation of the anticipated time to fly (TTF) to the next schedule point. The anticipated TTF is calculated by a Direct Course Error (DICE) program. The DICE is calculated as the schedule time at the next schedule point (IF or Gate) less the sum of the computed minimum time to fly to that point plus the current time. What this represents is the error (plus is early, negative late) from schedule time which would be incurred if the aircraft were to head directly to the next schedule point (i.e., in order to arrive on time, the aircraft should begin the turn to the direct course to the next schedule point, precisely when the DICE value reaches zero). Along both the minimum and maximum routes, two times are calculated: the first assumes a constant speed until slowdown (to the nominal) is required to satisfy the geometry data; and the second time assumes immediate slowdown to the nominal speed specified for the next schedule point. Thus, four different times to fly may be calculated.

1. TTFA: Minimum path with final slowdown.
2. TTFB: Minimum path with initial slowdown.

3. TTFC: Maximum path with final slowdown.
4. TTFD: Maximum path with initial slowdown.

The two extremes (TTFA and TTFD) represent the total controllability available between the aircraft's position and the next schedule point. All of the calculated times to fly, together with the schedule time at the next point, are used by the command generation function to determine the proper control actions to be taken. Schedule data provides the command generation function with information against which the aircraft's performance measures are compared. Very simply, the scheduling function calculates the estimated time of arrival at each schedule point -- the runway, final approach gate, IF, and FF -- based on a nominal path. The estimated time at the runway (ETAR) is then used to determine a landing sequence. Proper landing time intervals (LTI) are then calculated to determine the delay necessary. Finally, that delay is applied to the estimated time at the schedule points to define the scheduled times at those points.

Using the four inputs previously described, the command generation function is able to determine appropriate control actions for each of the M&S aircraft. The primary objective of the command generation function is to control each aircraft such that the schedule times are satisfied.

The M&S program provides two levels of FF control. The first level of control is performed by the metering function. After the schedules based on FP data have stabilized, the metering function will generate a proposed time of departure from the FF for each M&S controlled aircraft which requires delay of more than six minutes (a path dependent parameter).

The second level of FF control is provided by the command generation function when the aircraft is two minutes (parameter) from the FF. If not available, an updated ETA from the ARTCC is used. If no updated ETA is available, the initial ETA is assumed to be accurate.

When the aircraft is determined to be within two minutes from the FF, the command generation function will examine the schedule relative to the ETA. A recommended hold shall be generated if:

1. The delay to be absorbed exceeds some portion (y) of the available controllability (where (y) is a path dependent parameter), and

2. Holding is permitted at the assignment logical FF,

3. The scheduled delay exceeds three minutes, or if,

4. The preceding aircraft through that logical FF was scheduled to hold and is not scheduled to depart that fix before one minute prior to this aircraft's estimated time of arrival at the FF.

It is believed that an effective metering control capability will negate the need for holding at the FF.

The Command Generation function controls all scheduling operations. Gross scheduling of all Denver arrivals is performed when the Flight Data is first received. That schedule data is used to perform the metering function and to determine FF holding requirements. Rescheduling is requested when any new data is received, e.g., FP updates pertaining to ETA or aircraft type, or track activation, which permit computation of ETA. Command generation then requests tentative scheduling when each aircraft has penetrated the FF and is inbound to the IF. Thereafter, only schedule deletion or adjustments are requested. No "firm" scheduling is required.

Scheduling

The objective of the scheduling function is to determine an acceptable landing sequence and, based on that sequence, to determine schedule times at various points within the approach path. The schedule points are the runway, gate, inner fix, and feeder fix.

Scheduling is performed in support of the command generation function, i.e., command generation, based on aircraft performance, requests the establishment of schedules, schedule adjustments, and rescheduling. Like the command generation function, scheduling requires the geometry information, profile data and aircraft performance measures. Normally, the aircraft performance measures are anticipated values based on the profile and geometry data.

The scheduling function is divided into seven tasks.

1. Schedule Activation
2. Gross Scheduling
3. Tentative Scheduling
4. Rescheduling
5. Schedule Adjustment
6. Resequencing
7. Schedule Deletion

Schedule activation occurs when data are received indicating an arrival to the airport. That information is normally received via flight plan data from the En Route Center. It may also be received via data entry. The schedule activation task establishes a new M&S file and then calls on a scheduling task to establish schedule data.

The objective of gross scheduling is to determine the landing sequence and, based on that sequence, to determine estimated times at various schedule points and the delay which must be absorbed. The gross scheduling data is used by the metering function to determine a proposed time of departure from the FF for transfer to the En Route Center.

Generation of a gross schedule consists of first calculating an estimated time of arrival at the runway (ETAR). This requires calculating the time to fly (TTF), the sequence, base and final areas. Those times, together with the FP indicated ETA are used to determine the ETA at the runway (ETAR). The TTF calculations use the aircraft performance measurements which include both minimum and maximum times to fly. The times used for scheduling are the minimum times to fly (TTFM) plus a constant (the constant is an approach path dependent parameter which compensates for computational errors and/or the "desired" arrival path as opposed to "minimum" path).

Calculations regarding the TTF the sequence area (TTFs) is perhaps the most unpredictable segment since current ATC practices differ widely and are dependent upon load. Thus, if the aircraft is in active status (tracking), actual track speed is also considered, i.e., the lower of nominal or actual is used.

The calculated ETAR is then merged with the ETARs of all other scheduled aircraft. The merging process (an ordering by time) defines the gross landing sequence, i.e., "first-come-first-served at runway" criterion is used to define the arrival sequence.

After the landing sequence is established, a landing time interval (LTI) between the new aircraft (n) and the preceding aircraft (p) is computed. LTI is used to assure that sufficient separation is maintained between each pair of aircraft on final.

LTI is determined by computing four time intervals, the larger of which is used as the LTI. The four intervals are:

1. A minimum interval at the the gate, when the velocity of a aircraft p exceeds n.
2. A minimum interval at the runway, when the velocity of aircraft n exceeds p.
3. A minimum interval based on the runway occupancy time of aircraft p (profile data).
4. A minimum interval based on a controller keyboard entered gap request.

Computations 1 and 2 above consider the small/large/heavy class aircraft in addition to the keyboard entered minimum separation criteria, i.e., the LTI is the greater of the separations required to satisfy the runway occupancy time, the keyboard entered gap requested, the keyboard entered minimum separation, or the minimum separation determined from the separation matrix shown below:

<u>Separation Minima (nm)</u>

Trailing aircraft \ Leading aircraft:	Small	Large	Heavy
Small	3	4	6
Large	3	3	5
Heavy	3	3	4

Where aircraft classes are:

Small	less than	12,500 lbs. or less
Large		12,500 - 300,000 lbs.
Heavy	more than	300,000 lbs. or more

The LTI computation must provide for separation at the gate in cases where a slower aircraft is sequenced behind a faster aircraft. In this case, it may be assumed that (when the classes of aircraft are different) the high performance gate is outside of, or co-located with, the low performance gate, and the LTI shall be based on separation at the preceding aircraft's gate.

After the LTI is computed, the scheduled time at the runway (STAR), and the anticipated delay (if any) is calculated.

Figure 4 depicts the relationships of values to establish the Landing Time Interval (LTI).

Tentative scheduling is performed when each M&S aircraft is inbound from the FF. This is detected by the command generation function. Generally, the objectives of Tentative and Gross scheduling are identical; however, there are several significant differences since gross schedules are already established, the holding capability has been lost, and more precise data will be required by command generation.

Tentative scheduling must adjust the scheduled data based on the time out of the FF. Tentative scheduling must also adjust the landing sequence, where desirable, to incorporate approach path priorities, and identify exact schedule times at the IF and gate, for subsequent use by command generation.

Tentative scheduling first computes the minimum and maximum times to fly the sequence area (TTFsm and TTFsx) and establishes a new ETA at the Inner Fix. Using options exist: 1) the new ETAR could be used to determine a new sequence, or 2) the initial sequence could be used to determine a new value of delay. The second approach preserves the first come first served sequence (to the extent possible) even where there exists significant differences between the proposed time to depart the FF and the actual time through the FF and the actual time through the FF. The first approach would effect a priority relative to the time through the FF and permit a smoother arrival flow. A combination of these approaches, wherein a new sequence is assigned only when the current sequence cannot be attained even using the maximum times to fly, is incorporated into the design.

After the new delay has been defined, that delay is allocated to the sequence and base area.

Schedule adjustments consist of a forward or backward schedule slippage. These are requested by the command generation function when current aircraft performance measures indicate the aircraft will be early at the next schedule point, or when the aircraft will be late, by more than n seconds (parameter, based on the aircraft status), even when taking the minimum path.

The automatic resequence capability is provided to adjust the landing sequence when:

a. The first-come-first served criterion is undesirable because of differences in approach paths (approach paths may be assigned priority), or

b. Errors in the predicted aircraft performance resulted in a schedule which cannot be attained.

A manual resequence may also be requested via keyboard entry. In this case, one aircraft is specified, and that aircraft will interchange in sequence with the preceding aircraft. No resequence criteria used for the automatic resequence are applied. The new schedules for the identified aircraft and all affected subsequent aircraft are (re)established and, to assure that the manual action is not automatically reversed, the identified aircraft is flagged to inhibit any subsequent automatic resequence action. A manual resequence could result in unattainable schedules. This condition is indicated in the Alert Display when the aircraft is on the base leg, and prior to that, by large DICE values.

The schedule deletion is normally associated with the termination of M&S

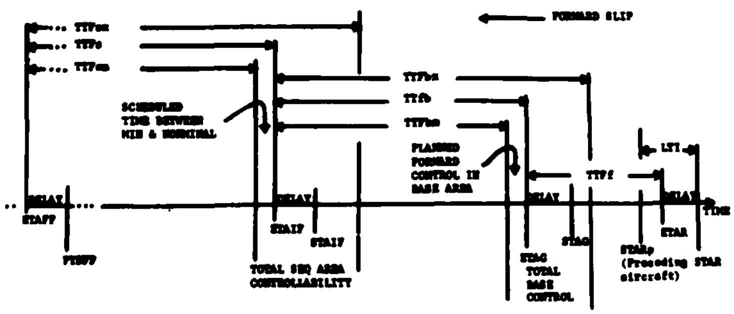

FIGURE 4, SCHEDULING DATA

control for a specific aircraft. Schedule deletion is also performed whenever a rescheduling action requires that the current data be dropped and the new schedule inserted. In either case, the task is the same; i.e., all schedule data will be erased from the sequence list and from the aircraft's data file. If the deletion is accompanied by a gap request, a gap will be provided (following the preceding aircraft), and no further schedule adjustments are required. If no gap is requested, the deletion action will effect a forward slip for all following aircraft. If any command is pending for the aircraft being dropped from the sequence, the command(s) will also be dropped. Note that this is the only condition in which a command can be automatically dropped.

METERING

Metering is defined as the process of adjusting the arrival flow to the airport acceptance rate. Many techniques are available to perform this function, including holding in the terminal area or at the handoff fixes. In most instances, however, the most desirable technique is to absorb delay in the En Route Center airspace. The M&S program provides the capability to aid in this metering process, using the existing ARTS/En Route digital interface.

M&S metering is accomplished in two parts: First, M&S will automatically issue proposed FF departure times (PTD) to the ARTCC, for individual aircraft, based on anticipated traffic loads; and second, M&S will issue recommended Holds to the terminal controller, for individual aircraft, based on the anticipated delays required, and on the recommendations for preceding aircraft through the same FF.

The first part of metering attempts to eliminate holding at the FF by allowing the en route controller to absorb the necessary delays within the en route airspace. The mechanism of holding aircraft at the feeder fixes is the final filter for a smooth metering of aircraft past the feeder fixes at the existing airport acceptance rate. The two parts of metering are described in the following paragraphs.

Flight plans for arrivals will be received by ARTS, from the ARTCC, 20 (ARTCC parameter) minutes prior to the anticipated arrival of its feeder fix. Ten (approach path dependent parameter) minutes prior to the ETA, it is assumed that all flight plans for aircraft which could land ahead of this aircraft have been received. Accordingly, the schedule computed for this aircraft should be fairly accurate. At this time, a PTD message will be automatically transmitted to the ARTCC if the scheduled PTD exceeds the ETA by more than three (parameter) minutes. The PTD may be used by the ARTCC controller to "burn-off" anticipated FF delays in en route airspace.

In case the ARTCC controller is unable to eliminate a FF delay while the aircraft is en route, or if for some other reason the scheduling algorithm determines that the aircraft must hold at its feeder fix, then a proposed departure time for the aircraft will be displayed together with a hold indicator. The ARTS controller may then verbally notify the ARTCC controller of the need for holding the aircraft at the feeder fix, or, the ARTS controller may absorb the delay if the aircraft is under terminal control.

Display Output - The M&S Display Output function is integrated into the ARTS III operational program and will add seven categories of display output data:

1. Command data
2. Sequence Data
3. FF Data
4. Wind Data
5. Parameter Data
6. Display of DICE
7. Separation Alert

M&S commands consist of recommended headings, speeds and altitudes for all M&S controlled aircraft. A single command for any aircraft may consist of one or more of these components, e.g., Heading, Altitude and Speed.

A heading component is presented as an L or R (left or right) followed by three numerics (005-360) indicating the magnetic heading to the nearest five degrees. An altitude component is presented as an A followed by three numerics indicating a "procedural" assigned altitude in hundreds of feet. A speed component is presented as an S followed by three numerics representing indicated airspeed, rounded to the nearest ten knots.

Command data is presented in the third line of the aircraft's Full Data Block (FDB) format. When more than one component is presented, all shall be contained in line three with a presentation priority, from the left, of: Heading, Altitude and Speed. Commands are presented at the controller's display and, like ARTS FDB data, the commands may be viewed at other displays only when that track is in handoff to, just accepted from, quick looked, or readout by another display.

Sequence data consists of an M&S generated landing sequence number, the assigned runway, and the required separation, in nautical miles, between this and the preceding aircraft.

The landing sequence indicator shall be a single numeric presented in place of the FDB position symbol. Sequence numbers are assigned on a system basis, 1-9, then 0 for the first ten aircraft in sequence, then 1 for the eleventh, etc.

Runway assignment consists of two numerics or two numerics and an L or R (e.g., 08 or 26L), and is presented in place of the scratch pad data in field two of the FDB format. The runway is automatically assigned (based on the selected geometry - 26L or 17L or manually modified via keyboard entry.

The minimum separation is a single number (1-9nm), obtained from the LTI computation, i.e., the minima separation matrix or the keyboard requested gap or the automatically generated gap. If the separation is greater than nine, 9 is presented. The separation is presented in field three of the FDB format, replacing the asterisk, and is timeshared with the handoff indicator. The separation pertains to the interval between this and the preceding aircraft and is presented for all M&S aircraft.

Feeder fix data is provided for all M&S controlled aircraft outside of the FF and within two minutes (parameter) of the ETA at the FF. The data consists of a time, in minutes after the hour, at which the aircraft is to depart the FF and hold indicator (HOLD) implying M&S has recommended a Hold.

For all M&S aircraft scheduled to hold, the FF data blinks for ten seconds (parameter), one minute (parameter) prior to the scheduled FF departure time. FF data is presented two minutes prior to the anticipated aircraft arrival at the FF and is dropped when the aircraft is detected as inbound from the FF.

FF data is continuously updated except that, for aircraft in Hold, changes to FF departure times will not be made after one minute prior to the scheduled departure time.

A tabular readout of the M&S wind data is provided. The readout is available only at the supervisory position. The data presented indicates wind Heading and Speed for both averaged National Weather Service and Adapted winds in each of the twelve wind collection areas. The number of updates (up to six) which were used to attain the adapted data is also shown.

A tabular list of miscellaneous M&S information is provided. Like wind data, the presentation is available only at the supervisory position. The list includes an updated count of M&S controlled aircraft, current geometry type, the separation criteria, the keyboard selected location of the high and low performance gates, and the runway occupancy times in seconds.

M&S provides the display of DICE in line zero of the FDB format. The DICE value consists of three characters (000-999) representing seconds. If negative DICE is presented as two characters preceded by an N, e.g., N32.

The presentation of DICE may be inhibited (on a display basis) via keyboard entry. DICE is not presented at other displays via quick look, readout, etc. If MSAW or Conflict Alert (CA) data is active for any aircraft, DICE data is inhibited until the MSAW or CA presentation is terminated. The display of DICE is also inhibited during all M&S-anticipated turns.

In addition to the Conflict Alert function already resident in the ARTS-III program, M&S provides an automatic visual alert whenever the program predicts that a violation of the computed minimum separation between the aircraft in process and the preceding aircraft will occur when the preceding aircraft is between the outer marker and the runway threshold. (Two facts should be stressed at this point: 1) the M&S separation alert might not be used when the program is operationally implemented due to the existence of the CA function and 2) M&S and CA are integrated into the ARTS-III software entirely independent of each other. In other words, the CA logic is not privy to aircraft intent as commanded by M&S, nor does the M&S logic attempt to provide separation except for final spacing when it issues a command. Determining the "compatibility" between these two functions is one of the goals of the current round of testing described in the Introduction. The M&S generated separation alert might result from a manually requested gap or resequence action which could not be accommodated within the M&S control capabilities, or it could result from M&S errors in predicting the aircraft performance. In any case, the presentation is the same. It is provided only for aircraft which are on base leg or beyond, and consists of a single character (M or T) followed by the predicted separation in nautical miles and tenths of nautical miles. The character indicates whether the violation will occur at the outer marker (M) or at the runway threshold (T). Because message is displayed in character positions four through seven of line zero of the FDB, it is overridden by an MSAW or CA message and is not presented via quick look, handoff or readout actions.

Adaptive Wind

The M&S control geometry is, of course, fixed and based on navigation aids and physical airport features such as runway location and alignment. In order to issue a command to vector an aircraft from point A to point B and have the aircraft arrive at point B when desired, the major external forces acting on the aircraft must be understood. The major external force acting on arrival aircraft is that of winds aloft. The M&S program, through its winds aloft logic, attempts to vector the aircraft so that the integrated effects of winds as the aircraft passes through space will place it at the correct altitude above the desired point on the ground at the correct time.

In other words, M&S must issue a heading and airspeed command corrected for the effects of winds such that the true ground path and ground speed will be as desired.

In order to do this, knowledge of the winds through which the aircraft will pass is essential. Because there is no means of measuring this quantity through ground based equipment, M&S uses a combination of National Weather Services estimates updated periodically and updates provided by monitoring a vectored aircraft's actual performance (heading and speed) versus commanded, and attributing the difference to winds. Obviously, considering the volume of terminal airspace, and the dynamic nature of the quantity, we are attempting to measure, it is an imperfect measure at best. The sections on Performance Goals and Current Efforts provide more information on winds aloft and M&S.

In addition to the above six M&S functions, other ARTS-III functions have been modified for M&S integration. These include Keyboard Inputs, Tracking, and Data Reduction and Analysis. We shall not delineate these changes in this paper because they are not essential to the understanding of M&S.

System Performance

The M&S performance has been analyzed in a series of tests at NAFEC simulating (in real time) the terminal area operational environment at Denver. ARTS-III equipment in the Terminal Automation Test Facility (TATF) was used to perform the data processing and display functions. The ATC Simulation Facility (ATCSF) was used to simulate the air situation and the data acquisition system, i.e., compute aircraft movement and generate scan-to-scan radar/beacon target reports.

The simulation scenarios were based on actual extracted data from Denver with realistic aircraft IDs, mix of aircraft weight classes, Feeder Fix assignments, and arrival rates.

Two different ILS runway approaches geometries were simulated. By changing the Estimated Time of Arrival (ETA) of the aircraft in the scenarios, two different scenarios were available for each of the two ILS approaches.

The simulation pilots in the ATCSF flew according to scenarios until overridden by controller commands (generated manually or by M&S as a function of the particular test).

For the manual (non M&S) runs, the controllers were actual active Denver controllers. For the M&S runs, the controllers were NAFEC employees with controller backgrounds.

The error environment was simulated by adding radar position noise (in range and azimuth) and response time delays on the part of controllers and simulator pilots.

Eight test runs were planned - four under manual control, four under M&S

control for comparison. Determination of potential operational performance was based on several key performance measures. The one measure considered most critical to increasing runway capacity is the landing time interval error:

Landing Time Interval (LTI) Error: LTI Error is the difference between the actual landing time interval and an after-the-fact determination of the optimum interval that could have occurred given the landing sequence employed, the actual aircraft performance as reflected by their track histories, and the restraints imposed by spacing minima criteria. The standard deviation of LTI error is the basic measure of performance. It is also the most critical measure because a large dispersion in LTI error indicates that the average time separation between aircraft provided by the M&S program must be increased in order to provide a buffer, α (a multiplicative function of LTI error) for control of the separation violation rate. Minimizing the LTI error σ (for a given average LTI and violation rate) provides for maximum theoretical safe runway landing rate (in aircraft per hour):

$$\text{Landing Rate} = \frac{3600}{(\text{ave LTI}) + \alpha(\text{LTI error } \sigma)}$$

where α is the multiplicative factor allowing control of the separation violation rates. For example, if α = 2, we would expect a violation rate of 2.28 percent (Figure 5).

The NAFEC tests produced the following results:

	No of Intervals	LTI Error Mean	LTI Error SD
Manual	128	8.03	17.04
M&S	117	3.76	10.07

These results are considered encouraging - they indicate a potential for runway capacity benefits via M&S. In spite of the encouraging results, a note of caution is in order. The above results do not indicate that we are ready to implement the M&S program immediately because of the following limitations.

1. LTI error, although a critical performance measure, is only one performance measure. Other important measures, independent of LTI error, include actual measured throughput (i.e., number of aircraft landed per unit time), percentage and severity of separation violations, delay imposed by the system and total time in the system. In addition, there exist more subjective, but equally important performance indicators such as equitable distribution of delay, sequence acceptability to controllers, data entry and display acceptability, etc.

Before a terminal M&S Program can be implemented, all these system performance measures (plus numerous specific measures for M&S component performance) must be analyzed.

2. The results of the testing already performed cannot be directly compared from simulation run to run, nor extrapolated to predict performance in the field because of limitations in simulation capability, lack of firm knowledge of the field environment and performance, and inherent inability to directly compare successive simulation runs without imposing unrealistic constraints in testing.

In order to make future testing more useful in predicting the implementation viability of the program, we are adding previously unavailable simulation realism. In

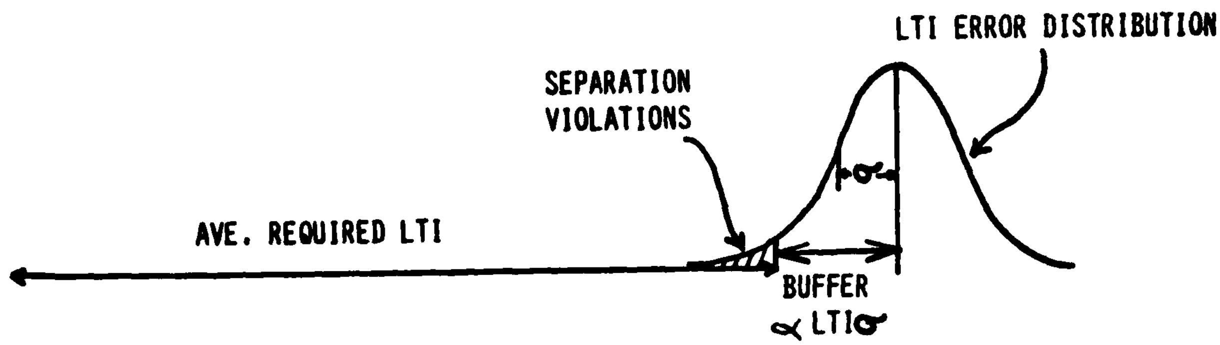

Figure 5. Separation Violation Relationships

the current round of testing, non-unity blip/scan ratios and errors in pilot/aircraft performance will be available. These errors include speed, heading and altitude errors plus errors in the nominal rates of change for the three quantities. Errors in arrival time, speed, position and altitude at the feeder fixes will also be provided. To support future testing, a field data collection and analysis exercise is being planned at two or three candidate sites in order to determine the current field environments and performance of current elements (aircraft and avionics, pilot, controller and ground equipment).

The inherent limitations of directly comparing one M&S simulation run with another stem from the dynamic nature of the M&S program. As various program and environmental factors such as winds, errors, parameters, geometries, etc., are changed, the landing sequence of the aircraft will change. This makes it very difficult to compare runs without attempting to compensate for sequence differences. Other factors which are difficult to compare are percentage and severity of separation or controllability area violations. In order to avoid the imprecision of attempting to compare runs, in the future, the tests will concentrate on comparing performance with predetermined performance goals based on existing (and as yet to be obtained) information on current "manual" field performance as well as theoretical potential performance (see next section).

Performance Criteria and Design goals

The previous section described some key M&S performance measures. A goal of M&S from the start of the development effort in 1974 was to perform to a specific level under *simulated environmental conditions*. These performance goals are listed in Table 1. Table 2 specifies some of the environmental conditions being used in the current NAFEC simulation testing efforts. Following the current test, a field data collection and analysis effort will be undertaken to enlarge the list of errors simulated and to improve the modeling capability of those already simulated.

Current Efforts

M&S is currently undergoing another T&E cycle at NAFEC. The objectives of this effort are to obtain under more realistic simulation conditions, qualitative and quantitative operational and technical appraisal of:

. M&S/Conflict Alert "Compatibility" (i.e., is M&S likely to induce a *substantial number of alerts* - false or otherwise, and if so, what are the alert characteristics)? The results will indicate whether a software interface allowing communication of

M&S System Design Goals		
Performance Measure	Criteria (1 sigma)	
	Error Free	System Errors
System Performance		
Inter-arrival Gap Accuracy	8 sec	11 sec
Arrival Rate (3 nm sep & min gate)	38/hr	35/hr
Item Performance		
Tracking - Straight Flight		
Heading Errors	5°	8°
Speed Errors	10 kts	10 kts
Metering Performance		
PTDFF Accuracy	$\pm$ 1 min max	$\pm$ 1 min max
Command Generation-Av/Aircraft	≤ 6.5	≤ 6.5
Adaptive Wind Accuracy		
Speed	15 kts	20 kts
Heading	15°	15°

Table 1. M&S Design Goals

ERROR SOURCE	ERROR
Data Acquisition (ETG) Errors	
Azimuth	± 0.12 1σ
Range	± 0.02nm 1σ
Target Declaration	
Straight flight	95%
Turning flight	90%
Aircraft Performance Errors	
Heading - Navigating A/C	Ø
Heading - Vectored aircraft	± 23ACPs (2°) 1σ
Heading change rate	± 0.25°/sec.
Initial Speeds - Scenario Scripted	script + speed error
Speed	± 4kts 1σ
Speed change rate	± 3.75 or ± 7.5 kts/min.
Altitude - Initial alt. scripted	± 150' 1σ
Altitude change rate	± 375' / min
Percent non profile arrivals (pop up)	scripted - 5%
FP errors in a/c type, FF, etc.	scripted - Ø%
Time @ FF relative to FP ETA	± 1 min max
Command Execution Errors	
Percent of M&S Command Executed	100%
Command execution delay time	12 ±4 sec uniform distribution
Wind Aloft (M&S Input vs. ETG) Errors	
Speed } variable by altitude	≤30kts
Heading } variable by altitude	≤40

Table 2. *M&S Simulation Error Environment*

intentions and determination of tactical responses to possible conflicts might be in order.

. Performance of M&S Winds Aloft Estimation Logic. This series of tests will determine the response of the wind estimation logic to simulated winds and the sensitivity of the program to errors in the wind estimation algorithm. The results will indicate if a more sophisticated means of determining winds is required.

. M&S Performance as a Function of Geometry. Two geometries will be observed: the "Trombone" Approach to Runway 26L and the modified "TALL" approach to the same runway. The results of this test will be used to determine if the theoretical performance improvements promised by the "fan" shaped base area delay absorbing paths of the TALL geometry can be demonstrated in a simulation environment.

. In addition to the technical evaluation of the various aspects of the program, an operational appraisal of the program will be performed. These tests will address questions such as acceptability of: sequencing logic, commands generated, display techniques, geometry constraints, M&S/CA compatibility, keyboard inputs, controller workload, etc.

Future Plans

Immediately upon completion of the current testing effort, we will begin the work required to define the operational requirements for an M&S capability integrated into selected automated terminal facilities. This will be a five part effort:

1. Site Data Collection/Analysis. - The current M&S program is designed to handle single airport, arrivals only, single runway operations at Denver. Although this is sufficient to demonstrate concept feasibility, it will not suffice in many operational facility without added functional capabilities. We need a program flexible enough to be readily adapted to conform to any operational or geographic situation encountered. Accordingly, one of the first steps toward implementation is a data gathering effort at several (2 or 3) candidate ARTS-III sites. The sites

will be selected to include all major operational and physical constraints we are likely to encounter.

At the sites visited we will obtain data on:

. Facility operations

- arrival/departure route structures, fix locations, etc.

- procedures for runway assignment, holding, missed approaches, absorption of delay

- special procedures (if any) based on: high/low performance class (e.g., runway assignment/restrictions, route, etc.); IFR/VFR conditions; ARTS configuration selection; runway(s) in use; and satellite airport traffic.

- terminal/en route procedures for flow control, holding, handoff, etc.

. Environmental conditions

- traffic loads (peak demand in IFR and VFR conditions)

- traffic distribution by gate, performance class, arrival/departure status and, for arrivals in a multi-airport facility, arrival airport

- variations in anticipated vs. actual speed on final, descent, deceleration and turn rates, and indicated air speed.

- performance of en route flow control and radar/beacon coverage

- performance of current system with regard to M&S performance measures

- physical restrictions in runways, arrival routes, etc. as well as possible flexibility in procedural changes

- meteorological forecast accuracies (forecast wind estimate accuracy)

. Implementation Impact

- adaptability of current M&S to the facility requirements

- identification and definition of all new capabilities required, e.g., multi-runway

- potential (or desirable) capabilities and their impact on performance, memory, schedule and test requirements

The data gathered will be used in the preparation of design and functional specifications and as the basis for improved fast and real time simulation tools.

This effort is expected to begin in January 1980, and the Site Analysis Report will be completed in August, 1980.

2. Analyze and Design Integration of M&S Function into ARTS-IIIA System. - The current M&S program resides in the basic ARTS-III System. By the time M&S is ready for implement, the ARTS-IIIA system will have replaced the basic system. Because of major differences between ARTS-III and IIIA (particularly in terms of executive control design and data base organization), a major study of required changes will be performed prior to preparing detailed design specifications. The first step in the analysis is to determine which of three alternatives is best for executive control of M&S:

. Full segmentation of all M&S tasks in accordance with the ARTS-IIIA Multiprocessor Executive (MPE). This will allow maximum parallel task execution.

. Retention of serial (possibly dedicated, as is done in current M&S) processing philosophy with MPE Modification for processor assignment, failure recovery, etc.

. Some compromise philosophy employing optimum benefits of each of the above techniques.

After choosing the preferred MPE integration approach, further analysis will be performed on the mutual impact of MPE AND M&S, failure recovery, and data recording and reduction requirements.

This task will begin in January, 1980 and the detailed requirements will be issued in November, 1980.

3. M&S Diagonal Slice Group (DSG). - A diagonal slice group is a concept for decision making in complex human/machine systems. Implementable M&S clearly falls into this category. The DSG is so named because it is a group of individuals with a common goal but with diverse backgrounds, responsibilities, and areas of speciality. When applied to M&S, this means that the group might be composed of individuals from service director to technician and backgrounds from any

FAA discipline. The group will be charged with tackling a number of critical, sensitive and even controversial issues which are as important and as difficult to solve as any technical problem remaining. It is felt that such a group, if properly utilized, will be able to anticipate and pose solutions to problems which would later surface and destroy or severly set back the M&S program at a huge cost in time and dollars.

The issues to be addressed by the DSG include:

. Controller/machine interactions and responsibilities

. Impact of M&S on maintaining controller proficiency

. Should revolutionary procedural changes optimized for automation be introduced initially or will it be a less abrupt, evolutionally transition?

. Display requirements and options

. Handling departures

. VFR versus IFR operations

. Criteria for determining which sites will be eligible for M&S

. Pilot/controller performance/sensitivity to M&S derived procedures

The DSG will meet periodically throughout 1980.

4. Future Technology and Cost/Benefit Analysis. - This task is planned to be performed by the Office of System Engineering Management (OSEM). The task involves definition of M&S's role in and interaction with future new systems and technology to be introduced over the near and long term. The system which must be addressed include Wake Vortex Avoidance System (WVAS), Microwave Landing System (MLS), Area Navigation (RNAV), Discrete Address Beacon System (DABS)/Data Link, Cockpit Display of Tactical Information (CDIN), etc. A cost benefit study would consider FAA training and workload impacts, potential full savings, and delay savings to aircraft (air carrier and other) and passengers.

5. Implementable M&S. - The above four tasks will provide the basis for a decision regarding the development of an implementable M&S program. If the development is approved, the implementable M&S will be designed, coded and thoroughly tested at NAFEC using improved fast time and real time simulation capabilities for modular and system testing. When the program has been sufficiently tested at NAFEC, it will be taken to the field for lead site implementation. Following a thorough field evaluation, the program and documentation, including site adaptation procedures will be provided to the FAA operating services for implementation at the remaining sites selected. This activity should be complete in 1985.

Summary

The Terminal Metering and Spacing Program is designed to automate a complex human thought process requiring assimilation of large amounts of data in an error filled environment, and issuing strategic and tactical commands to insure that airport runways are used in an equally safe and more efficient manner than is done by today's controller. Clearly, it is a monumental task to automate such a complex function. The technical challenge in some instances are overshadowed by human and environmental issues. In spite of these obstacles, progress is being made that will lead to the decision regarding implementation of this capability at selected high density airports by the mid 1980s. The program promises sizable payoffs in terms of fuel savings, delay reduction, capacity increases, increased utilization of sophisticated airborne and ground based equipment and controller productivity.

Acknowledgement

The author wishes to express his appreciation to Mr. John R. Talley, Chief, Terminal Branch (Acting), ATC Automation division, who authored this paper in the 1978 edition of the SRDS Progress Report. In addition, Mr. Dennis C. Kisby, Principal Application Analyst for the UNIVAC Defense Systems Division of the Sperry Rand Corporation must be acknowledged as the principal figure in the design oand success to date of basic M&S. His dedication to and enthusiasm for this program has our sincere gratitude.

ELECTRONIC TABULAR DISPLAY SUBSYSTEM (ETABS) DEVELOPMENT PROGRAM

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BIOGRAPHY

Donald L. Scheffler, recently retired from government service, was a mathematician in the En Route Branch, ATC Systems Division, SRDS. He received his B.S. in mathematics in 1954 from the University of Chicago. Before joining the FAA in 1959, he spent 5 years at the Ballistics Research Laboratory, Aberdeen Proving Ground, Maryland, where he worked on two of the early digital computers, EDVAC and ORDVAC. From 1961 to 1966 he was employed as a senior systems analyst with American Airlines and TRW. He rejoined the FAA in 1966 as Chief of the Computer Programming Section in the ATC Development Division where he headed the software development for the ARTS III Terminal Air Traffic Control System.

ABSTRACT

This paper describes the Electronic Tabular Display Subsystem (ETABS) development program. The objective of the ETABS program is to apply computer and electronic display technology in the replacement of the flight strip printers and paper flight progress strips now in use at all Air Route Traffic Control Centers (ARTCCs). Through the use of electronic displays, processors, and touch entry devices, ETABS will automatically provide non-radar flight and control data to the Data ("D") Controller at each en route control sector.

BACKGROUND

Since the inception of the Air Traffic Control system, the method of posting flight data information to the air traffic controller has been the paper flight strip. Before the introduction of the present NAS Stage A ATC System, flight data information was entered and updated manually by pencil on the flight strip. The present system uses electro-mechanical flight strip printers which, under computer control, print initial and updated flight data on paper strips and distribute the strips to the proper sectors. This system requires mounting ("stuffing") of the strip by hand in the flight strip holders, placing the holders in the desired position in the flight strip bay, updating the flight data by pencil, and entering update information into the computer by means of a manually operated keyboard device. This is a cumbersome operation which consumes much of "D" Controller's and "A" Controller's time.

The existing sector in an Air Route Traffic Control Center is normally staffed by a two-person team comprising a Radar ("R") Controller and a Data ("D") Controller. Although this two-person team is the normal mode of staffing a sector, three-person teams are sometimes employed at certain sectors during periods of high traffic activity. In the three-person team an additional Tracker ("T") Controller performs manual operations and flight strip processing while the "D" Controller performs interphone communications and assists the "T" Controller. The two or three-person sector team is supported by an "A" Controller who mounts and delivers flight strips to each sector team. One "A" Controller typically services two sectors.

At the current air traffic level, approximately 8,000 controllers are required to staff the existing sectors in the Air Route Traffic Control Centers. A recent study (Reference 1) indicates that with the forecasted growth in air traffic the controller staff will need to be increased significantly with the creation of new sectors (sector-splitting) which will be necessary to meet future traffic demands. The study shows that the implementation of

ETABS will result in an increase in controller productivity with a consequent reduction in sector staffing growth rates. Based upon an ETABS implementation in the 1984-1985 period, present value cost savings through 1999 are estimated at $433.7 million.

To achieve the objectives of ETABS, the FAA prepared an Engineering Requirement (*Reference 2*) and issued a Request for Proposals for System development in March 1978. Proposals were received from industry in May and a contract was awarded to Sanders Associates, Inc. on January 30, 1979.

PROGRAM PRODUCTS

The ETABS engineering model will be installed at the FAA National Aviation Facilities Experimental Center (NAFEC) by the contractor. This system will consist of two interface processors to provide a high speed, redundant interface with the NAS En Route Central Computer Complex (CCC) and six sector positions, each consisting of an electronic tabular display, touch entry device, keyboard, and display processor to interface the sector with the interface processor. See Figure 1.

The ETABS Engineering Model will be designed to replace the present "D" sector position equipment at 6 of the 24 sectors in the NAS En Route Laboratory in the NAFEC System Support Facility and will perform all the functions of a full-scale ETABS system.

The ETABS Engineering Model will be evaluated and used to determine the effectiveness of:

1. *The interface with the NAS En Route* Central Computer Complex; that is, the integrity of the mutually interdependent hardware and software designs of ETABS and the Central Computer Complex.

2. The display formats on the electronic displays which will present flight plan data to the "D" and "R" Controllers.

3. The ease of controller data entry to the flight data base, primarily through the use of touch entry devices (activated by touching the display with a finger) and software controlled display selection lists to guide the controller.

4. The methods of transitioning into a facility operational state from the present manual flight progress strip methods in the field.

5. The fail-safe, fail-soft design with a non-volatile flight data display system in providing for continued operation during equipment failures.

The products resulting from the ETABS evaluation will include a comprehensive evaluation report and a validation of the ETABS Cost Analysis (Reference 1).

The final product will be a technical data package that will contain the information and documents required by the FAA Airway

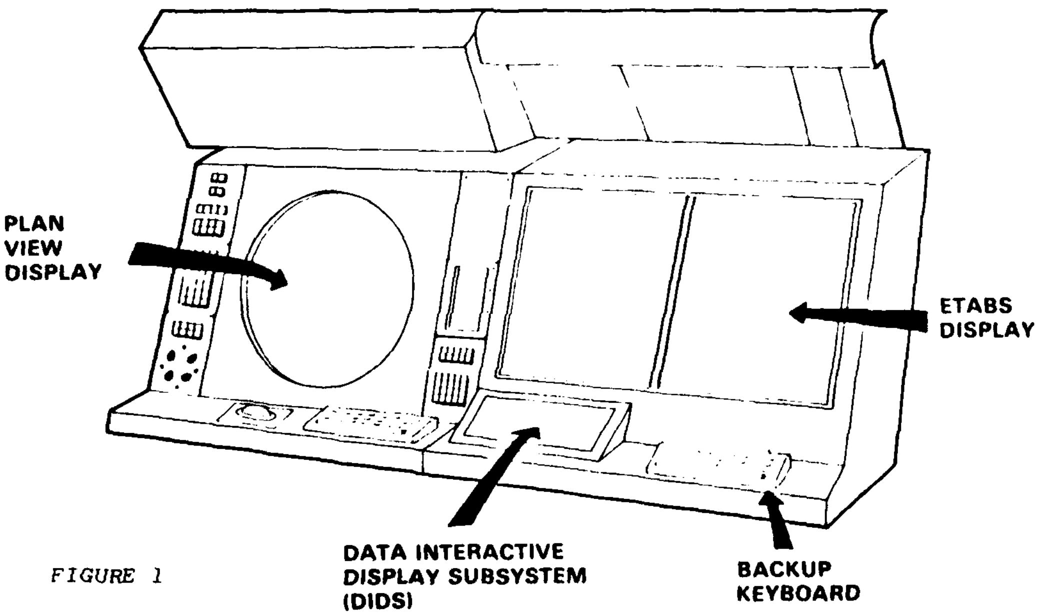


FIGURE 1

FIGURE 1, EXPERIMENTAL ETABS FACILITY

Facilities Service to prepare specifications for competitive procurement and implementation of a production version of ETABS.

TECHNICAL APPROACH

ETABS consists of the computers, displays, and message entry resources necessary to support the en route sector positions. A distributed processing network concept is used to accept, process, and distribute flight planning data to recipient sector positions and to accept, process, and transmit controller originated messages to the NAS En Route Central Computer Complex (CCC).

The primary ETABS computer resources are two Interface Processors interfacing directly with the CCC and with smaller display processors located at each sector position. Figure 2 illustrates the ETABS configuration consisting of redundant equipment within a Common Equipment Group and Sector Equipment Groups, one for each sector position. Reference 2 contains a detailed description of each ETABS component.

ETABS hardware interface devices connected to the Interface Processors provide communication paths to the CCC Input/ Output Control Elements (IOCE's) and respond to commands from the CCC.

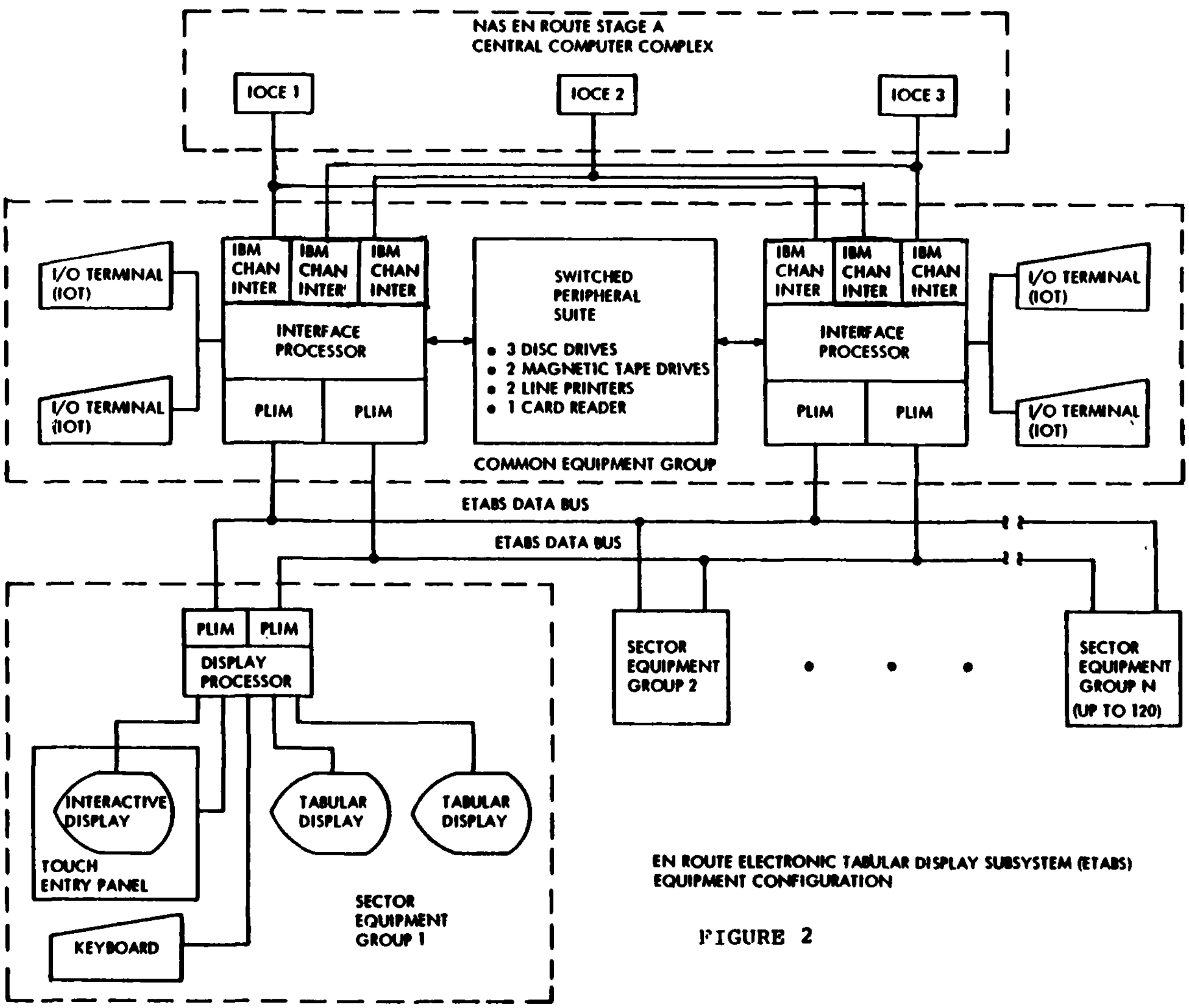
a. Common Equipment Group:

The common equipment group will perform the following functions while on-line:

1. Provide communications with the CCC.

2. Provide redundant storage of all operational flight and adaptation data.

3. Distribute data to and accept data from the Sector Equipment Groups.



EN ROUTE ELECTRONIC TABULAR DISPLAY SUBSYSTEM (ETABS) EQUIPMENT CONFIGURATION

FIGURE 2

4. Service requests from the Sector Equipment Groups, such as:

a. Program load requests.
b. Data base regeneration requests.
c. Supplemental data requests.

5. Multiplex air traffic controller input messages from the Sector Equipment Groups to the CCC.

6. Provide intersector communications.

7. Generate hard-copy data via the line printers.

8. Provide configuration management of ETABS components including automatic reconfiguration of equipment following a system component failure.

9. Record performance and operational data on magnetic tape for later analysis.

10. Communicate with system operator through the Input/Output terminals.

The Common Equipment Group will perform the following functions while off-line:

1. Perform computer program compilations and assemblies for both the Interface and Display processors.

2. Run maintenance programs to diagnose faults in both the Common Equipment Group and the Sector Equipment Group.

3. Process simulation data from on off-line CCC configuration.

4. Perform assemblies of adaptation data and output adaptation sub-sets for use in the operational program.

b. Common Equipment Group Hardware:

The Common Equipment Group (CEG) is comprised of the following components, configured as a fully redundant fail-safe system. See Figure 3.

1. Interface Processor - Each Interface Processor is a Perkin-Elmèr Model 3220, a general purpose 32 bit mini-computer that is software compatible with the Interdata (Perkin-Elmer) Models 7/32 and 8/32.

The Model 3220 Processor is configured with 512K bytes of Metal Oxide Semiconductor (MOS) memory with a seven bit code appended to each 32 bit word, which allows for correction of all single-bit errors and detection of all double-bit and many multiple-bit errors. Battery backup to maintain the contents of memory for 6 minutes after loss of power is provided. Memory may be expanded in 256K byte increments up to a maximum of 4 million bytes. All memory is directly addressable.

The Model 3220 Processor meets all immediate ETABS processing requirements plus sufficient excess capacity to accommodate additional future operational requirements. The unit has the capability to support several multiprocessor systems such as interprocessor communications links and shared memory banks. The Model 3220 has sufficient capability to allow at least a 100% expansion in the number of magnetic tape units, card readers, printers, and I/O terminals.

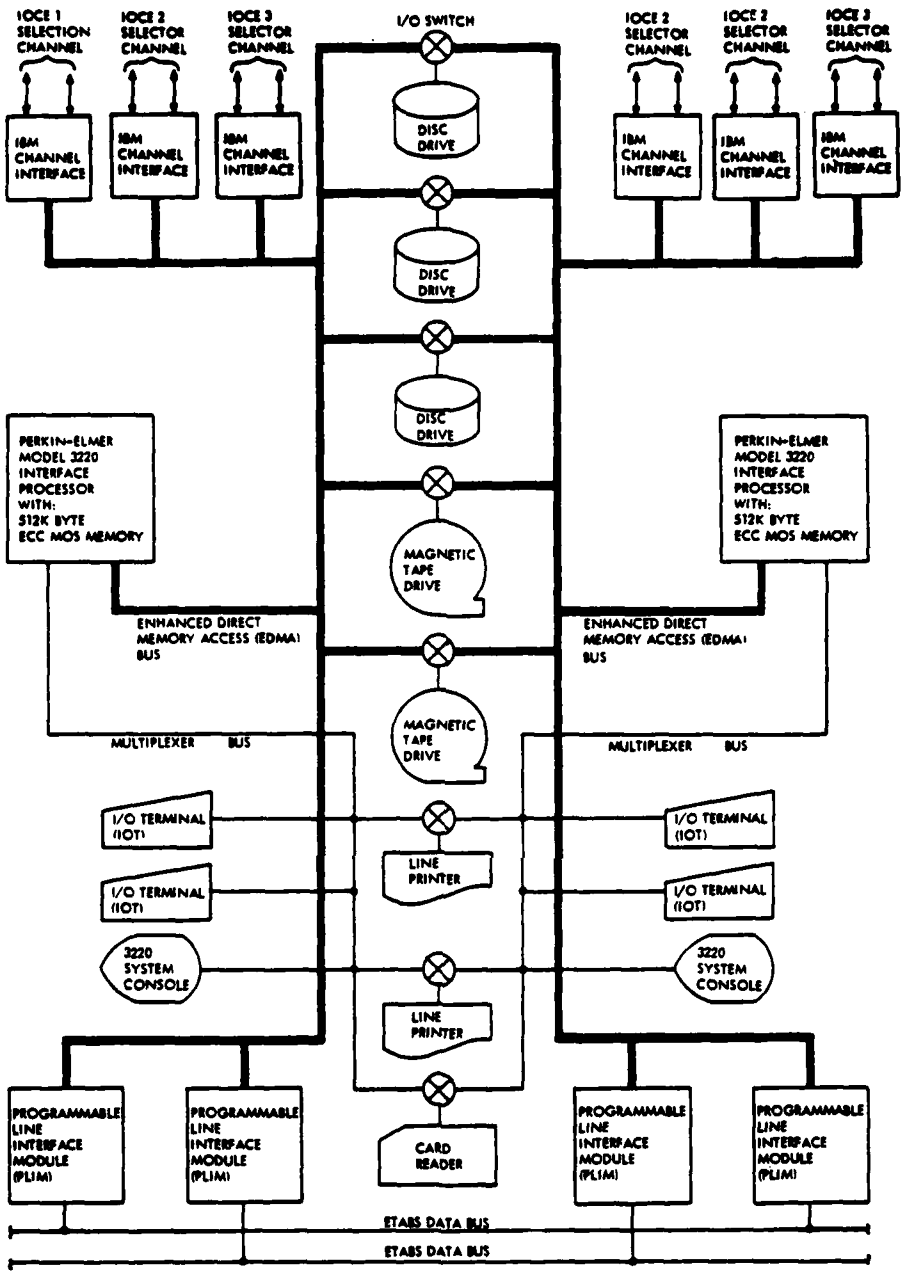
Failure isolation and repair is enhanced through extensive maintenance features which include a memory error logger, self-test and a multi-media diagnostics package which provides diagnostics for the processor, memory and all peripherals. A cathode-ray tube display at the system console facilitates operator interaction with the computer system.

2. Selector Channel Interface - The Selector Channel Interface is a standard off-the-shelf Interdata product which plugs into the Model 3220 Processor chassis and provides for direct communiations with the En Route Central Computer Complex. The Interface is capable of 500,000 bytes per second transfer rates. Six Selector Channel Interfaces are required to provide redundant interfacing for the two Interface Processors with the three IOCEs of the En Route Central Computer Complex.

The interface hardware is programmable to permit loading parameters for control of interface sequences. This relieves the Interface Processor from considerable overhead requirements while allowing timely responses to the channel and status monitoring of the Interface Processors. Another feature of this interface is the built-in resident off-line test capability for each of the six interfaces. The tester is completely isolated from the channel when off-line and assures electrical isolation from the channel when in the test mode. While in test, problems may be isolated by exercising a full range of interface functions in conjunction with the Interface Test Program Package. The test status and conditions are monitored on a maintenance panel.

The Selector Channel interface consists of three 15-inch modules which plug into the Model 3220 Processor chassis, a 5.25 inch high Bus and Tag Cable Entry Panel, and a 5-inch by 5-inch Interface Maintenance Panel.

3. Input/Output Bus Switch - Sixteen I/O Bus Switches are used to control the configuration of the Interface Processor peripherals. Two switches are required for each set of peripherals which may be switched under program control or with a manual override. A Light Emitting Diode



ETABS
COMMON EQUIPMENT GROUP
FIGURE 3

(LED) indicator on the switch lights when that switch is selected. Each Bus Switch is contained on a 7-inch module which plugs into an expansion chassis. The Bus Switches are powered from sources in a configuration which allows power down and removal of one bus switch of a pair without disrupting normal operation of the peripheral. The manual override for three pairs of I/O Bus Switches is contained on a 1 3/4-inch panel. The three switches allow for power off, program mode, and selected processor mode. The switch panel provides for flexibility in maintenance.

4. Disc Storage Unit - The Disc Storage Unit includes a fully formatted removable disc cartridge, the drive mechanism, a disc control unit, and power supplies. Each disc control unit is configurable to each Interface Processor under software and manual control. Each disc has a capacity of 10 million bytes with an average seek time of 33 milliseconds. The data transfer rate

is 312,500 bytes per second. Each disc unit can be expanded to over 40 million bytes.

The disc unit features zero spindle speed sensing, a variable frequency oscillator, fault detection logic, end of travel interlock, automatic gain control and an optical transducer for reliability and fault detection. The disc unit is modularly designed with forced air cleaning and disc cleaning brushes to reduce maintenance.

Each disc unit has high-speed parallel access to the processor selector channel through the I/O Bus Switch. Data integrity is assured by extensive error detection circuitry. The disc unit has error rates of one soft error for each 10 to the 10th bits, and one hard error for each 10 to the 12th bits, after 3000 complete disc processes.

Maintenance is aided through a diagnostic package which tests the disc unit both individually and in conjunction with the system configuration. The disc unit will be mounted in an equipment rack.

5. Magnetic Tape Unit - The Magnetic Tape Unit includes the tape drive, operator controls, a tape control unit, and power supplies. The tape recording formats are fully compatible with those of the IBM Type 2401-03, 9-track tape unit used in the En Route Central Computer Complex. The tape control unit can be switched to either Interface Processor manually or by software control. The Magnetic Tape Unit uses an 800 bit-per-inch format and operates at 45-inches per second.

Extensive error checking is included with condition checks for write overflow, read after write error, cyclic redundancy check, longitudinal redundancy check, and vertical parity errors. The magnetic tape unit is connected to the I/O Bus as a parallel byte oriented input/output.

Front access is provided for easy access to test points. Self-loading vacuum chambers use a long-life brushless blower motor. With quick release reel hold-down knobs, straightline tape threading, and automatic on-line operation, the unit offers high operator convenience.

The Magnetic Tape Unit, designed to produce minimum noise levels, is mounted in an equipment rack. All major subassemblies are packaged for rapid replacement to provide maximum serviceability. Maintenance is further aided by a diagnostic package which tests the units individually and in conjunction with the system configuration.

6. Line Printer - The Line Printer includes the printer mechanism, operating controls, control unit, and power supplies. The chain type printer prints at a speed of 430 lines per minute with 132 character per line. The printer has a full numeric and alphabetic (upper and lower case) plus all ETABS special characters. The printer prints from 1 to 6 part forms compatible with forms used in the IBM 1403 printer. Each line printer control unit may be switched manually and under software control to either Interface Processor. The line printers are connected to the processors using a parallel byte oriented technique with a parity bit for error checking.

The printer is housed in a free-standing sound-deadening cabinet with locking casters. A built-in self-test maintenance panel provides the means to exercise all printer functions in an off-line mode. Additionally, a software diagnostic package will test the printer's interaction with the system configuration.

7. Input/Output Terminal - The I/O Terminal includes an integral keyboard, printer mechanism, operator controls, control unit, and power supplies. The terminal permits input and output of 128 different printable and control characters at a rate of thirty characters per second. Each terminal is switchable manually and under program control to either Interface Processor.

The I/O Terminal features easily interchangeable print caps for a variety of fonts. It is interfaced with the standard teletype 20 milliamp current circuit using the eleven bit serial protocol of one start, eight ASCII, and two stop codes.

The terminal is a compact self-contained package which is pedestal mounted. Maintenance is aided by a diagnostic package which tests each terminal individually and in a system configuration.

8. Card Reader - The Card Reader includes the reading mechanism, operator controls, control unit, and power supply. The unit reads standard eighty-column, twelve-position cards in ANSI-X3.26-1970 card format at a minimum rate of 400 cards per minute. The Card Reader may be switched manually or under software control to either Interface Processor. A 1500 card stacker and a Hollerith to ASCII hardware converter are provided.

The reader has a fiber optic self-cleaning read station and utilizes data verification techniques to prevent loss of data. Throughout the read operation, a "light test", "dark test," and card motion test are continuously performed to verify the operation of the reader.

The Card Reader is a compact, lightweight, free-standing unit which has easily accessible switch controls and a full range of function indicators to ease operation interface and monitoring.

9. Sector Equipment Group

Interface - Two Sector Equipment Group Interface modules are included in each Interface Processor. Each of the redundant Programmable Line Interface Modules (PLIM) is capable of driving up to 128 Sector Equipment Group Display Processors using a high speed serial multidrop technique. The capability of adding any number of Sector Equipment groups, up to a total of 128, to the ETABS system is resident in the basic hardware. The one megabaud data rate is sufficient to handle initial requirements with expansion capability.

The simplicity of the multi-drop technique gives high reliability and reduces maintenance problems. The output from the Interface Processor PLIM is connected to the Display Processors over standard RG 59 cable using BNC connectors. At each display processor, the connection is made with a "T" connector to the high impedance line interface module and is terminated into a 75 ohm load at the final connection. With this technique, a PLIM may be easily disconnected from an on-line cable without disturbing other units operating on the line.

Each PLIM consists of the modem for cable driving, the transceiver for line protocol, and the I/O controller for high level protocol; all contained on a single 15-inch printed circuit module which plugs into the Interface Processor selector channel. There are four BNC connectors located on the modem components which have the same buffered signal at each output. Each output signal is capable of driving 32 loads on the multidrop in half-duplex communications.

A failure or power off condition in any PLIM will not affect data to the other PLIMs. To ensure this, logic has been designed for failsafe conditions and, for added assurance, a disconnect relay is contained on the card. Extensive error checking is inherent in the communications protocol which provides efficient transparent data transfer on the multidrop bus. The data is checked with a Cycle Redundancy Check (CRC) code and the sequencing of protocol is checked for errors.

In addition to the connection to the Sector Equipment Groups, cross coupling to the opposite Interface Processor gives a means for status communications between the processors. This important link may also be used for line monitoring and test data generation to aid in equipment maintenance.

c. Sector Equipment Group:

The Sector Equipment Group will be capable of performing the following functions:

1. Provide storage of air traffic control sector-related data base.

2. Format and display required portions of the data base.

3. Provide an interactive data entry capability.

4. Manage communications with the Interface Processor.

d. Sector Equipment Group Hardware:

The sector Equipment Group subsystem includes (See Figure 4):

- A Tabular Display consisting of two 25-inch indicators.
- A 12-inch Interactive Display with a touch entry panel.
- A Keyboard.
- A Sanders GRAPHIC 7 display processor with a self-contained memory unit.

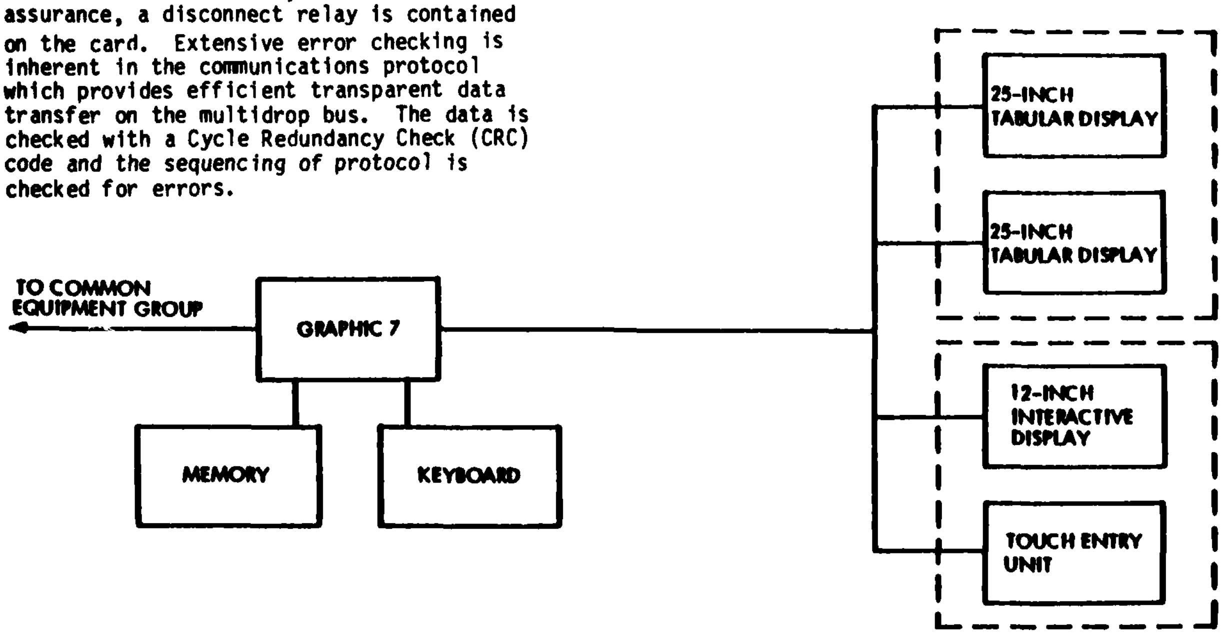


Figure 4 SEG Configuration

The equipment is housed in a console conforming to the space allowance defined by the Console Turret Lower Assembly presently in use. The GRAPHIC 7 display processor and associated memory are mounted below the shelf, and are also accessible from the front.

The Sector Equipment Group redundantly interfaces with the Common Equipment Group through two high speed intelligent Programmable Line Interface Modules (PLIM), to gain a high degree of isolation and redundant buffering from processors in both the Common Equipment Group and other Sector Equipment Groups. Each programmable line interface module, connected to a multi-dropped serial data link, has the ability to receive data in a high-speed broadcast mode for increased system response time.

1. Tabular Display and Processor - The GRAPHIC 7 Display Processor with two large cathode ray tubes provide a high performance refreshed display system. It features a programmable display system to present the required data in a 96 symbol per line by 84 line format on its display surface while maintaining the high image quality required by the air traffic controller. These two display surfaces are mounted vertically, and are separated by less than 3 inches.

The presentation on the cathode-ray tube display surface consists of stroke written characters which are defined electrically to the horizontal and vertical inputs of the indicator. The indicator unit consists of a 25-inch rectangular cathode-ray tube, identical horizontal and vertical deflection system assemblies, a low voltage power supply, a high voltage power supply and function modules containing signal line isolation, linearity correction, amplifier/tube protection, and video amplification.

2. Interactive Display - The Interactive Display consists of a 12-inch random access indicator unit and an associated Sanders developed touch entry panel which is a modular assembly that mounts on the front of the 12-inch display.

The indicator unit utilizes proven off-the-shelf electronic designs identical to that found in the Tabular Display indicators, thus enhancing the maintainability and logistics aspects of the Sector Equipment Group. A 12-inch display surface provides the required symbol quantity while minimizing the viewer inteference with the Tabular Display that would be present if a larger display surface were used.

The Touch Entry Device is a Sanders development which has solved the problems common to touch entry systems by minimizing the parallax problem while providing a glass surface as the man/machine interface. The Sanders approach uses light beams that emit in the infrared zone and are invisible to the eye, while two sets of light beams approximate the curvature of the cathode-ray tube and form light planes that are tangential to the tube, thus minimizing the parallax problem.

The Touch Entry Device is impervious to noise and has an ambient light detection feature which compensates for extreme ambient light conditions. The Device has a RS232 interface format which is the standard for GRAPHIC 7 Display Processor peripherals.

The Interactive Display will be positioned on a swivel mount so that the Sector controllers can select the most efficient positioning of the Interactive Display.

The Interactive Display which is removable for maintenance purposes, is mounted on the shelf assembly.

3. Keyboard - The keyboard, which is presently being used in an Air Traffic Control environment, contains the standard upper case alphabet, a numeric pad, and special keys for the support of Air Traffic controller operations. Each key depression will generate an ASCII code which is passed to the Display Processor through a RS232 interface link.

The keyboard contains solid state contact keys to ensure precise and long lasting operation. Individual backlighting is provided with adjustable intensity capability.

Liquid spill protection is also provided for this self-contained assembly which mounts into the shelf assembly of the console.

e. System Cables:

The primary system level cables for the ETABS system are the Central Computer Complex (CCC) to Common Equipment Group (CEG) cabling and the Sector Equipment Group (SEG) to Common Equipment Group Cable.

1. CCC to CEG Cable - The CCC and CEG cable will be the standard Bus and Tag Cable procured from IBM. There will be multiple sets of Bus and Tag Cables to accommodate the redundant CCC selector channel interfaces.

The cables are directly compatible with both the 9020 channel and the Perkin Elmer Selector Channel Interface: no modifications to any hardware are required.

2. CEG to SEG Cable - The hardware resident in the Common Equipment Group is capable of driving 128 Sector Equipment Groups without modification. Each Interface

Processor has two (one redundant) Programmable Line Interface Modules (PLIM'S) which drive the 128 Sector Equipment Groups and also provide intercommunication with the other Interface Processor for status transfer and test.

The physical cable will be the standard RG-59 B/U 75 ohm coaxial cable which will be terminated in BNC type connectors. Various cable lengths will be available to interconnect the SEG with the CEG; the design will accommodate distances of 300 feet from the Common Equipment Group to the Sector Equipment Group.

d. Software Architecture:

1. CEG Software Architecture - The CEG Software architecture is based on the use of Perkin Elmer's Dynamic OS/32 MT real-time multi-tasking operating system. ETABS processing functions will be performed by event driven application programs, using the executive task-scheduling and I/O services of OS/32MT. Program module interfaces include core-resident buffers, message queues, and parameter lists. In general, operational messages will be formatted as ASCII character strings. Information flow in the CEG is illustrated in Figure 5. Error detection is performed at all levels, including link-level protocol, processor instruction traps, memory parity, data validity and interprocessor

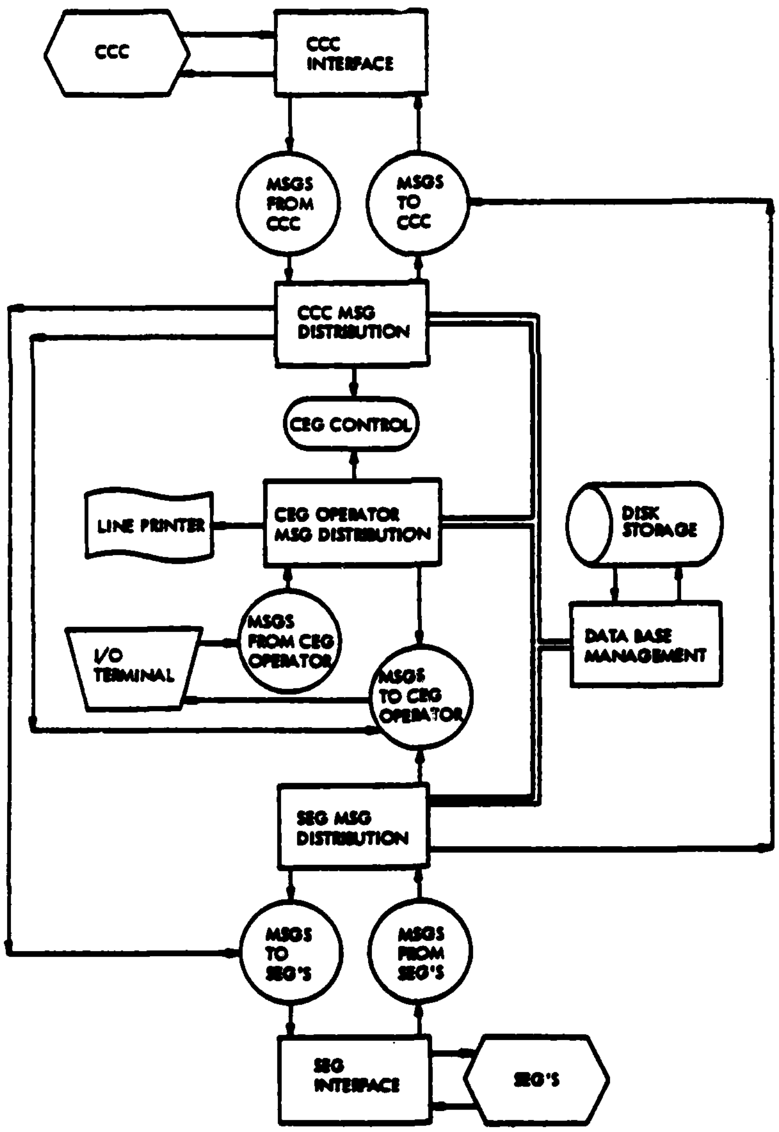


FIGURE 5 CEG Information Flow

monitoring. Contingency mechanisms include automatic peripheral and Interface Processor reconfiguration, emulation of an unavailable CCC, and resectorization.

2. SEG Software Architecture - The SEG Software architecture is based on the use of a modified graphic Operating System developed for the GRAPHIC 7. Termed the SEG Monitor, the modified graphic Operating System contains standard features plus special display management functions. SEG processing functions will be performed by event driven application programs, using task-scheduling and I/O services of the Monitor. Program module interfaces include memory buffers, message queues and parameter lists. Operational messages will be, in general, formatted as ASCII character strings. Display refresh code will be formatted ASCII character strings with special characters for display refresh control and character size intensity, and blink control. Information flow in the SEG is illustrated in Figure 6. Error detection is performed at all levels, including link-level protocol, data validity, memory parity and hardware function monitoring. Contingency mechanisms include reconfiguration around certain hardware failures and failure mode processing in the event of a CEG/SEG communications failure.

SUMMARY OF PROGRAM STATUS

The current schedule for ETABS development is depicted in Figure 7. The Contract with Sanders Associates, Inc., was initiated in January 1979 and design has progressed through the Preliminary Design Review and the Critical Design Review phases.

Delivery of the Engineering Model to NAFEC for test and evaluation is expected in July 1980. Testing and evaluation is scheduled to be completed in July 1981. Final results of tests and evaluation with ETABS technical design data will be documented in the form of a Technical Data Package which will be sent to the FAA Airways Facilities Service in November 1981 for use in procurement of production systems.

ACKNOWLEDGEMENTS

The contributions of Mr. Peter Damiano, ETABS Program Manager for Sanders Associates, Inc., for the technical data in this paper are gratefully acknowledged.

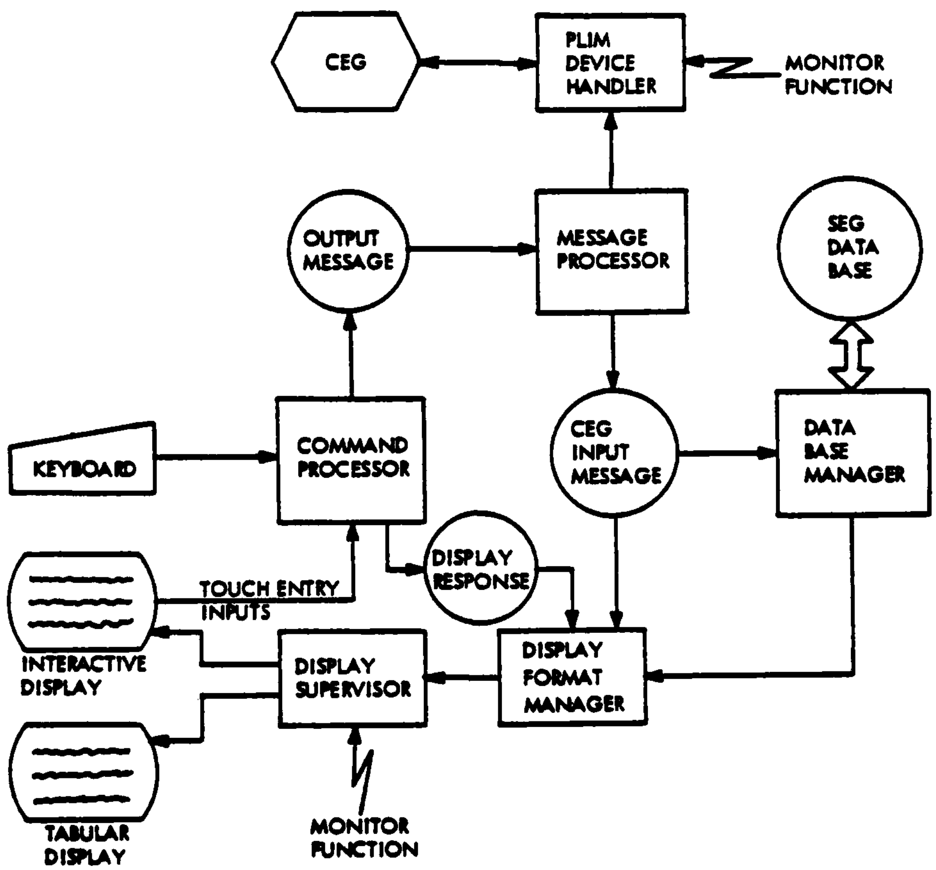


Figure 6 SEG Information Flow

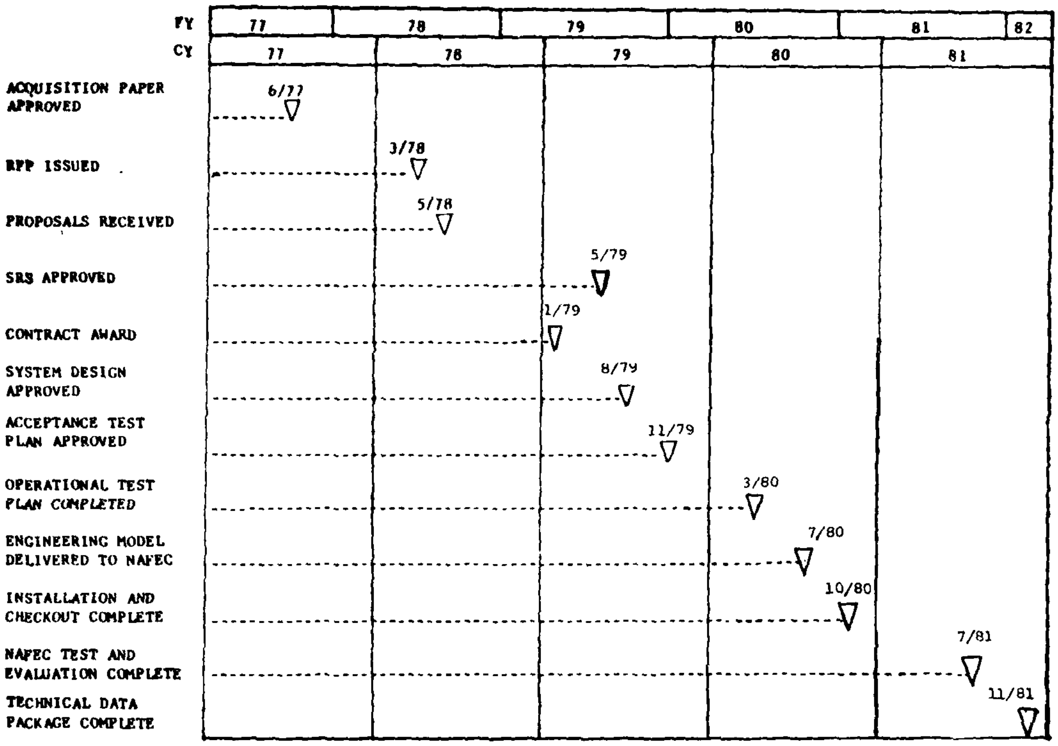


FIGURE 7

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EN ROUTE MINIMUM SAFE ALTITUDE WARNING FUNCTION (E-MSAW) INTEGRATED WITH THE CURRENT NAS AUTOMATION SYSTEM

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BIOGRAPHY

James P. Dugan, recently retired from government, was a computer system analyst within the En Route Branch of the ATC Systems Division SRDS. Before joining the FAA in 1959, he spent 12 years at the Ballistic Research Laboratory at Aberdeen Proving Grounds, Maryland, where he worked on some of the early digital computers. From 1959 to 1966, he was at the FAA's National Aviation Facilities Experimental Center (NAFEC), New Jersey, and in 1966 moved to the Data Processing Branch of the ATC Development Division SRDS.

ABSTRACT

The En Route Minimum Safe Altitude Warning (E-MSAW) function will provide in the NAS En Route Computer System an automated aid to Air Traffic controllers, alerting them to situations when tracked aircraft are below or will soon be below predetermined minimum safe altitudes. The current E-MSAW development effort evolved from a Terrain Avoidance project developed by SRDS for feasibility testing at the Albuquerque ARTCC in 1976.

This paper describes the development products and activities as well as the technical approach followed by the E-MSAW project.

Development, evaluation, and demonstration activities have been completed at the National Aviation Facility Experimental Center (NAFEC), Atlantic City, New Jersey. Following this, the E-MSAW computer program was integrated with the latest En Route Operational Computer Program (Version 3d2.8) in preparation for the field evaluations at the Memphis and Albuquerque Air Route Traffic Control Centers as shown in Figure 1.

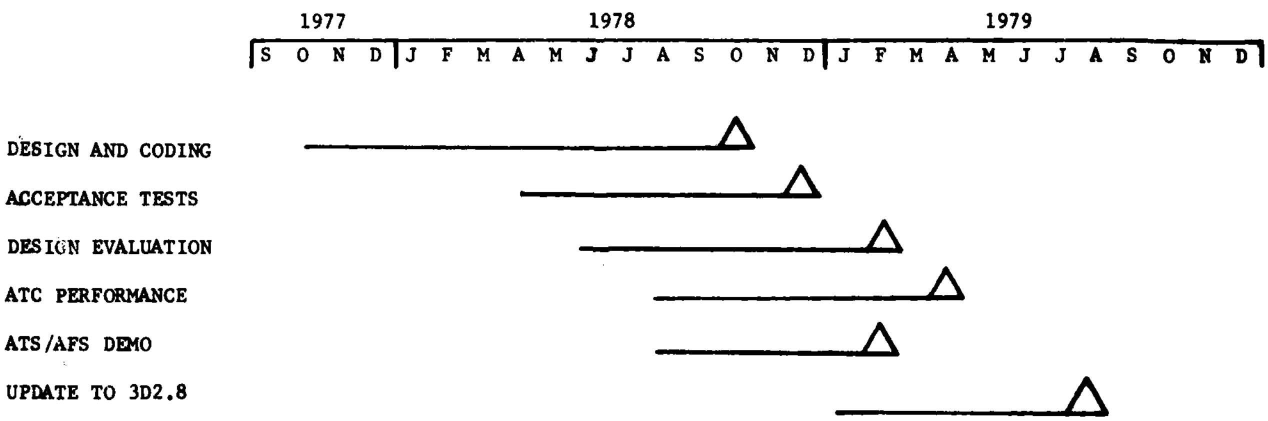

FIGURE 1, DEVELOPMENT SCHEDULE

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ACRONYMS

ACES	Adaptation Control Environment System
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
E-MSAW	En Route Minimum Safe Altitude Warning
EWA	E-MSAW Warning Altitude
HGFA	High Gross Filter Altitude
MEA	Minimum En Route Altitude
MGFA	Middle Gross Filter Altitude
MTA	Minimum Track Altitude
MVA	Minimum Vectoring Altitude
MWA	Maximum Warning Altitude
NAS	National Airspace System
NAS 3d2.8	Version 8 of the National Computer Program
RSB	Radar Sort Box
TAV-05	Terrain Avoidance, fifth version
VFR	Visual Flight Rules
UDS	Universal Data Set
VLAT	Vector Lookahead Time

BACKGROUND

This paper contains a discussion of the objectives and design of an En Route automation enhancement called En Route - Minimum Safe Altitude Warning (E-MSAW).

The current E-MSAW development effort has evolved from a Terrain Avoidance (TAV-05) project developed by SRDS and tested at the Albuquerque ARTCC in 1976. TAV-05 was basically a feasibility study and provided the background and foundation for operational requirements upon which the current effort is based.

The E-MSAW function as currently designed will provide alerts to air traffic controllers of violations and impending violations of airspace defined as hazardous for Air Traffic Control (ATC) operations (Reference 1). E-MSAW airspace will be adapted directly from the En Route Minimum IFR Altitude Sector charts prepared by the facility's operations staff.

The Minimum IFR Sector Altitudes are derived from considerations of the terrain, obstructions, traffic flow, and operational considerations.

E-MSAW airspace is defined subject to the following constraints:

1. Each ARTCC will have the capability of adapting a maximum of 200 E-MSAW areas, bounded by closed polygons.

2. Each E-MSAW area will be defined by at least three but not more than ten line segments. End points will be defined by latitude and longitude. An E-MSAW area may be defined within another E-MSAW area.

3. Each E-MSAW area will have a safe altitude associated with it, defined to the nearest 100 feet.

4. Each E-MSAW area may have up to ten airports associated with it. The provision is made in the initial implementation to allow definition of airspace to eliminate departure and arrival flights near airports and airport complexes.

TECHNICAL APPROACH

The baseline system used for developing the test, evaluation and demonstration of the E-MSAW function at NAFEC was NAS model 3d2.4. The E-MSAW function uses, as primary input, radar tracking data as computed and stored by the Automatic Tracking function (X,Y tracking) and the Altitude Tracking (Z tracking) function. E-MSAW processing sequences on a subcycle basis to operate after the tracking function has been completed, thus avoiding destructive interference in accessing the tracking tables. The main body of the E-MSAW program is required in core during each tracking subcycle (6 seconds) and is dynamically buffered.

a. Filter Design

A major technical problem addressed in computer program design relates to the efficient comparison of extrapolated flight paths for all eligible tracks with upwards of 2000 line segments defining the horizontal cross sections of E-MSAW areas. In dealing with this problem, the technique employed is to apply filters of increasingly finer mesh. The E-MSAW function operates periodically, inspecting the complete track file on a cyclic basis.

An adaptable High Gross Filter Altitude (HGFA) is specified. This is an altitude high enough so that level, climbing and descending aircraft above it would not be projected to enter any E-MSAW airspace within the filter processing time interval. At this first filter, VFR flights are also screened out; i.e., flights with no assigned altitude and no filed flight plan. There will, however, be E-MSAW processing of VFR tracks which have a Mode-C reported or a controller-entered altitude, when the controller specifically requested it.

A middle gross filter altitude is utilized, similar to the high gross altitude filter, to further reduce the E-MSAW processing load. The Middle Gross Filter Altitude (MGFA) is set at a lower level to screen out aircraft above this altitude for climbing and level flights and inspects them on the same periodic basis as indicated above for flights above the High Gross Filter Altitude (HGFA). Within this level, however, descending flights could conceivably project into E-MSAW airspace before the next periodic inspection of flights above MGFA, and therefore, are candidates for further E-MSAW processing. (See Figure 2).

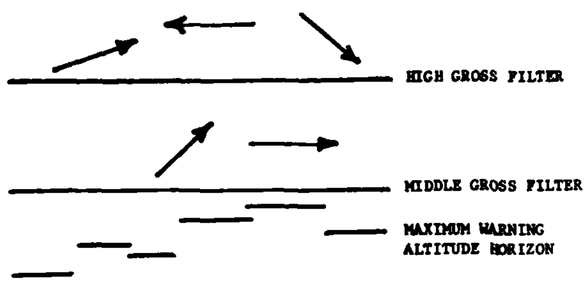

FIGURE 2, GROSS ALTITUDE FILTERS

To facilitate the comparison of track position and velocity with E-MSAW airspace, each 3-10 sided polygon, capped by a E-MSAW Warning Altitude (EWA) describing the airspace, is related to the Radar Sort Box (RSB) grid by the off-line processing of the adaptation assembler. (See Figure 3).

Since the center area is completely covered with EWA assignments, each RSB, the 16x16 nautical mile box used in radar/track correlation, must contain a minimum altitude, below which track projections may generate an E-MSAW alert. If, however, the aircraft's departure or destination point can be matched to an airport adapted to the E-MSAW area (i.e., the EWA), the alert is inhibited. A RSB can either be totally encompassed by one E-MSAW area, or be intersected by one or more E-MSAW area boundaries, implying that several minimum altitudes prevail within the RSB. The adapted minimum altitude, in the simplest case, is a single EWA which is identical to the MVA. There are situations where the EWA could be lower than the MVA due to the Minimum En Route Altitude (MEA) of an intersecting airway being lower than the prevailing MVA of the airspace encompassing the airway. In this case, the E-MSAW airspace would be adapted so that the EWA would reflect the dimensions of the Minimum En Route Altitude (MEA)

A more complex situation prevails when more than one E-MSAW area intersects within an RSB, meaning more than one EWA is associated with the RSB. This implies employment of a Maximum Warning Altitude (MWA) based on the higher EWA, for the sort box and some additional processing to detect the boundary where the EWA altitude changes and which EWA altitude applies to the current projected position of the candidate track. This additional processing is called area violation detection (Fig. 4).

b. <u>Processing Sequence</u>

The total number of tracks are logically divided into subsets based upon an adaptable parameter, the High Gross Filter Interval (HGFI). Subsets are formed by considering only every HGFI (e.g., if HGFI=3, then every third) track and incrementing the first track on each execution by the HGFI filter. This results in examining 1/HGFI of all tracks every HGFI subcycle.

The gross filters described above are followed by an additional, finer filter known as the E-MSAW Sort Box filter. This filter serves to limit the number of E-MSAW areas, which must be examined for possible violations, to those areas which overlap the RSBs along the track's

MVA CONTAINS AIRWAY WITH LOWER MEA

MVA	5000
AIRWAY MEA	2000

DEFINED BY THREE E-MSAW AREAS

1. ABCO1 AT 5000
2. ABCO2 AT 5000
3. ABCO3 AT 2000

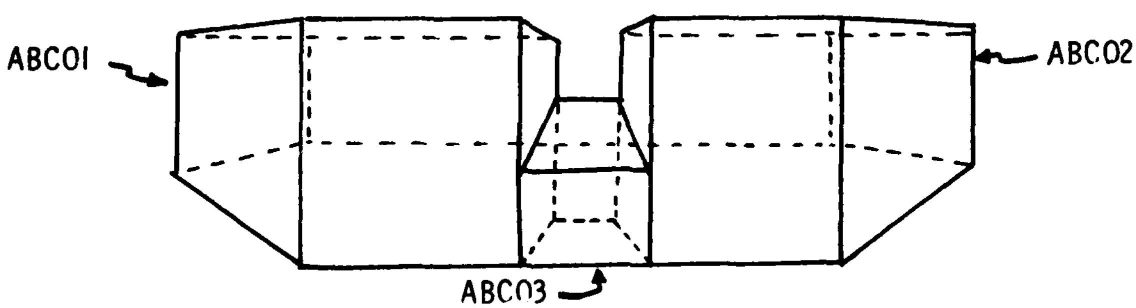

FIGURE 3, E-MSAW AREAS

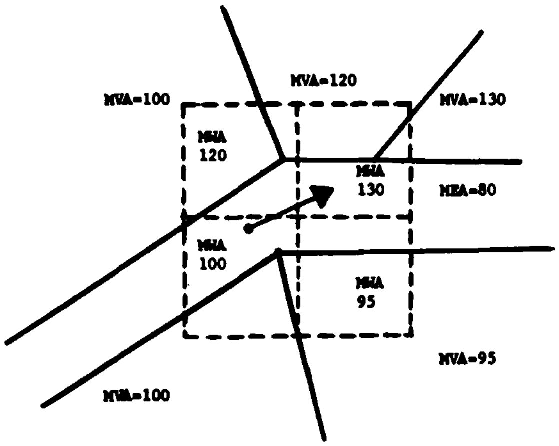

FIGURE 4, SORT BOX FILTER

projected route of flight. The Minimum Track Altitudes (MTA) achieved by the altitude track for each sort box traversed in the lookahead time interval (VLAT, a parameter) are computed and compared to the maximum warning altitude stored by adaptation for each Radar Sort Box. If the MTA's are above these maxima for all RSBs traversed, the track is rejected from further processing. Otherwise, the polygons associated with the RSBs are examined for penetration by the track over the VLAT time interval. (See Figure 5).

Finally, if the track becomes eligible for an alert with an E-MSAW area that has an associated E-MSAW adapted airport list, then this list is searched for a match with the associated arrival/departure points. If a match is found, then the alert is inhibited for the given E-MSAW area.

c. <u>COMPOOL Table Design</u>

Processing efficiency is the main consideration in a table design that maps the polygons and their associated altitudes and airports into Radar Sort Boxes (RSB's). The tables contain pointers and are chained to permit rapid retrieval of polygon boundaries and to access switches which control the selection of three distinct violation detection algorithms designed to service specific RSB/polygon configurations:

1. Polygons with only convex angles in the RSB. (See Figure 6).

2. Polygons with only concave angles in the RSB.

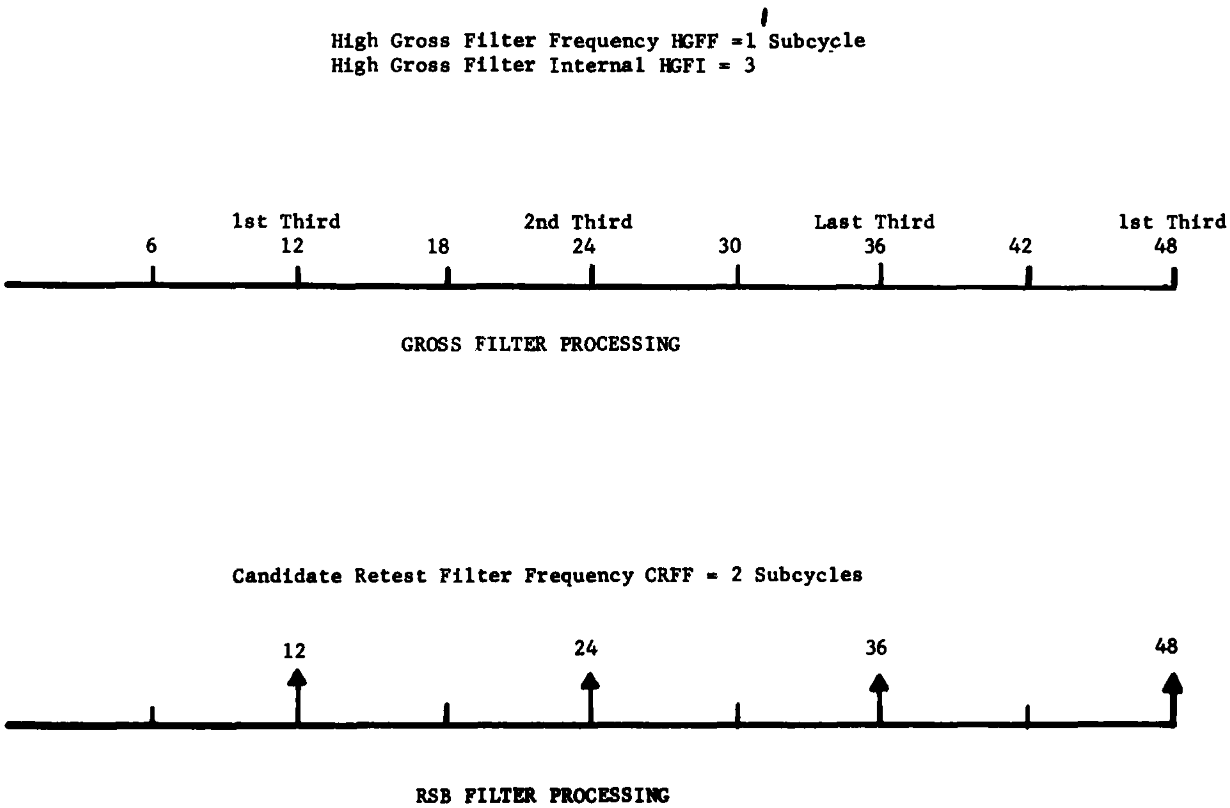

FIGURE 5, E-MSAW PROCESSING SEQUENCE

3. Polygons with mixed concave and convex angles in the RSB.

Adaptation tables are constructed off-line by the Adaptation Control Environment System (ACES) to represent E-MSAW airspace mapped into RSB's by the following stored information:

1. The total number of the polygon line segments that intersect the RSB.

2. The polygon vertices which make up the line segments that intersect the RSB - defined in clockwise direction.

3. An indication whether the entire polygon is completely within the RSB.

4. The altitude associated with the polygon.

5. An indication of which algorithm applies to this polygon in this RSB.

If the maximum capability to adapt 200 polygons, each with ten vertices, is required, then a maximum of 15,000 words will be needed to map the polygons into the Radar Sort Boxes. These data are stored on disk and buffered only when required by execution of the violation detection algorithms.

Information from the adapted tables can be rapidly retrieved by an initial, simple calculation to determine the RSB's intersected by the ground track of the aircraft. Determination of whether the ground track will penetrate the E-MSAW polygon is facilitated by the definition of a basic procedure called ORIENT which defines the orientation of a point to a line. (See Figure 6).

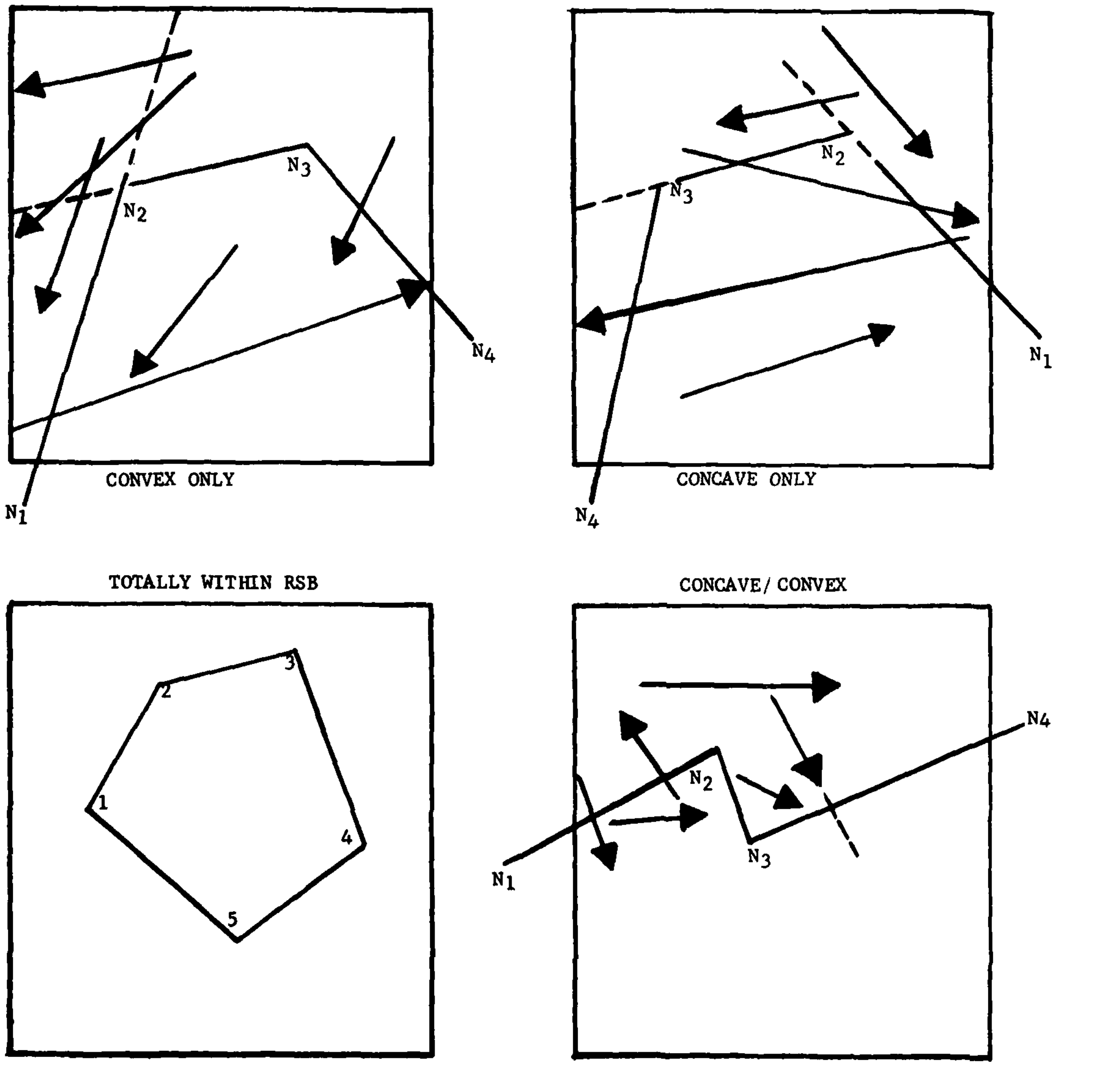

FIGURE 6. VIOLATION DETECTION ALGORITHMS

d. Console Inputs and Display Outputs

Many of the console inputs, display routing and control parallel those of the En Route Conflict Alert function.

An alert is normally not displayed on its first detection occurrence. An alert situation must be detected in two of three consecutive computation cycles to qualify for display. An Alert Redetection Validation Mask (ARVM) is the parameter which controls the display of alerts.

E-MSAW alerts are displayed on the Controller's PVD by displaying the letters "MSAW" blinking in field E of the full data block. The letters "MSAW" blink during the occupancy interval.

A double-written line is displayed from the track position to the E-MSAW point of violation, at the end of which the altitude violated is displayed.
When the conditions for alert are satisfied, the E-MSAW alert is routed to the controlling sector and if the track is in HANDOFF status, also routed to the receiving sector.

It is possible by supervisory inputs to turn the E-MSAW function off for the entire Center or to turn off the display of alerts for an individual sector.

The controller is provided with two types of suppression of individual alerts enterable from his console:

1. Alert Suppression suppresses display of an alert on a specific flight relative to a specific E-MSAW area. The letters MOFF would appear in field E of the data block. The suppression is discontinued on termination of the alert situation.

2. Indefinite Suppression inhibits alerts on a given flight center-wide and indefinitely. The letters MIFF will appear in field E of the data block to remind the controllers of the action taken.

The Alert Suppression and Indefinite Suppression are reversible actions. (See Figure 7).

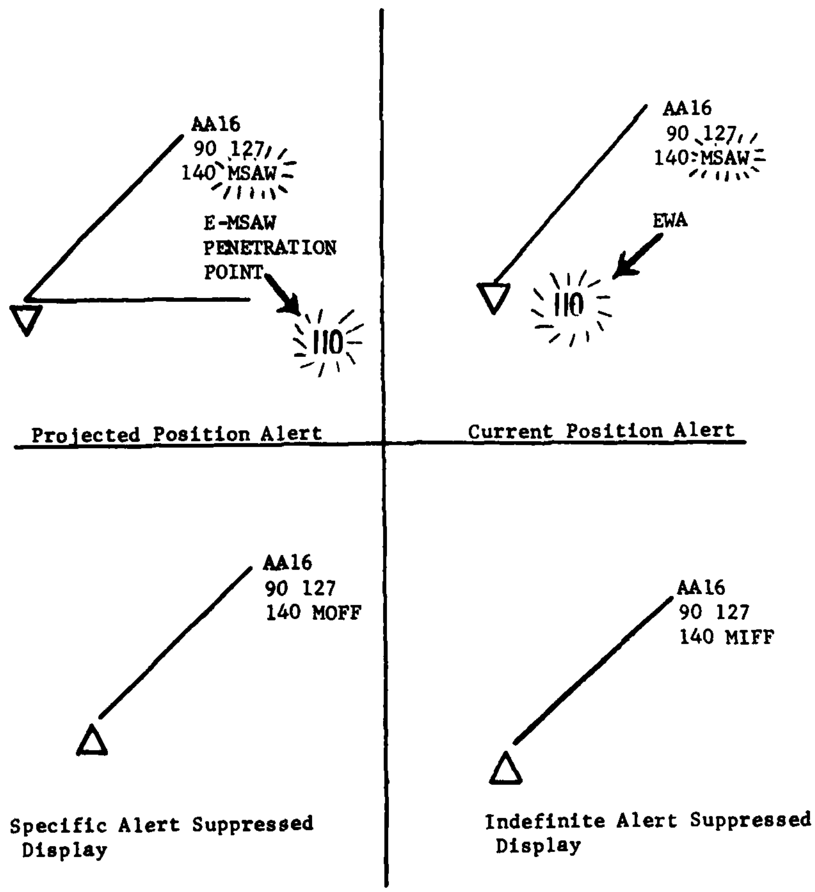

FIGURE 7, CONTROLLERS DISPLAY FORMAT OF ALERT

PROGRAM STATUS

Coding of the E-MSAW function into the NAFEC version of NAS 3d2.4 with its Universal Data Set (UDS) commenced in March 1978 following approval of the Computer Program Functional Specifications (Reference 2) and the Program Design Specifications (Reference 3). An extensive test program followed delivery of the computer program. NAS 3d2.4 is a duplicate of the NAS ATC Operational Computer Program that was in field use from March 1977 through March 1978.

Three series of tests were conducted at NAFEC: Acceptance (Product Assessment) Tests by Computer Sciences Corporation, Design Evaluation Tests by the MITRE Corporation and ATC Application Tests by NAFEC.

Acceptance (Product Assessment) tests verified the technical integrity of the E-MSAW function and its compliance with design data contained in the approved Computer Program Functional Specifications.

Design Evaluation tests measured the performance of significant elements of logic which constitute the E-MSAW function, including a parametric performance analysis.

The parametric performance analysis was a critical part of the Design Evaluation tests due to the effects these parameter settings have on alert processing delays, filter effectiveness, processor utilization and the number of false alarms. Key parameters and their recommended values are as follows:

High Gross Filter Increment - This parameter as set will logically divide the total number of tracks into subsets. Processor utilization can be effectively managed through this parameter selection with each subset being processed in accordance with the selected subcycle. This parameter can be set at intervals of 1 through 4 and will initially be set at 3. This means that initially one third of all the tracks in the system will be processed through the filter design each subcycle frequency.

High Gross Filter Frequency - This parameter although independent of the one above is related. This parameter can be set from 1 through 4 subcycles (1 subcycle is 6 seconds) and will determine at what time and frequency the selected subsets will be processed. Initially the High Gross Filter Frequency will be set to 1 subcycle.

Vector Lookahead Time - This parameter can be set at a maximum of 180 seconds at 1 second intervals. Initially it will be set at 90 seconds and will provide the projected interval for determining whether the ground track will intersect an E-MSAW polygon. This setting is crucial in that too large a setting may result in excessive false alarms. Conversely, this parameter must be high enough to permit controller/pilot communication of the E-MSAW warning and the pilot's reaction to it.

Candidate Retest Filter Frequency - Tracks passing the gross E-MSAW filtering process become candidates for detailed violation detection. Detailed violation detection is performed every Candidate Retest Filter Frequency tracking subcycles. This parameter can be set from 1 through 4 subcycles and will initially be set at 2 subcycles. All tracks, identified as candidates will be considered for detailed detection of violation against E-MSAW areas every 2 subcycles.

These and other parameters were evaluated using a gross model of E-MSAW and system analysis recordings from the Albuquerque and Memphis ARTCCs. Although these recording samples were small, results were satisfactory leading to the selection of these initial parameter settings for the field tests at these two centers.

The Design Evaluation also analyzed central processor utilization. This was accomplished by determining the instruction mix timing for the filtering and detection software, the processing time for processing one track and then obtaining the utilization from a track load. Under a 222 track load, the Memphis ARTCC would utilize .9 percent of a 9020A and the Albuquerque ARTCC would utilize 1.3 percent of a 9020A for processing E-MSAW software modules. Both of these 9020A locations are triplex systems.

The 9020D central processor utilization was not evaluated during the design evaluations but measurements were made at the completion of the development cycle. The 9020D was measured using the development software and a universal data set at NAFEC driven by standard simulation load tapes. At a 222 track load, E-MSAW software modules will utilize .5 percent of a 9020D computer configuraton. This was based on an average number of nine alerts which is considered to be high for the en route system.

In summary, with careful E-MSAW area adaptation and selection of filter parameters, impact of E-MSAW on the en route system should be minimal.

ATC application tests evaluated the controller-computer interface. Simulated operational tests were also used to gain additional insight into the response time distribution for the computer-controller-pilot system when E-MSAW advisories were provided. The controllers in this test environment were able to work effectively with the E-MSAW capability, and they recommended only minor changes to the system.

Following successful completion of the

evaluation tests at NAFEC, the E-MSAW computer subprogram was integrated into system tape (NAS 3d2.8) and turned over to the Air Traffic Service for their field evaluation at the key sites (Albuquerque and Memphis).

ACKNOWLEDGMENTS

The E-MSAW development has required the skill, knowledge and participation of the Air Traffic Service, The MITRE Corporation, Computer Sciences Corporation, and NAFEC along with other elements of SRDS.

In the preparation of this paper, the assistance of Mr. Anthony Severino of ARD-140 and Mr. Stephen J. Hauser, Jr., of The MITRE Corporation is gratefully acknowledged.

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EN ROUTE DISPLAY RECORDING/PLAYBACK

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BIOGRAPHY

Mr. Parker Harris, a registered professional engineer, is a Program Manager in the Systems Research and Development Service, ATC Systems Division. He has had extensive experience in the field of en route automation. Before joining the FAA in 1959 he was engaged in the design and testing of flight simulators with the Engineering and Research Corporation in Riverdale, Maryland.

ABSTRACT

The ability to record and later replay what had been seen on a controller's display has always been looked upon as a desirable goal. A number of experiments had been conducted in the past 10-15 years with this goal in view, but the equipment was usually unreliable, expensive, and the results of questionable value. Techniques previously used most often were either photographic film or analog TV video recording. Recently, however, technology has advanced to the point where equipment reliability is no longer a significant problem and high speed digital recording methods are able to produce acceptable results. A breadboard recording/playback system was designed and built by the FAA at the National Aviation Facilities Experimental Center (NAFEC). It had the ability to record and playback one display at a time. The breadboard model was highly successful and resulted in the FAA initiating the design and fabrication of an Engineering Model. The field or production version of this system will be modular and able to record 36 displays per module.

List of Acronyms

NAFEC	National Aviation Facilities Experimental Center
ATC	Air Traffic Control
SAR	System Analysis Recording
AFS	Airway Facilities Service
SRDS	Systems Research & Development Service
ATS	Air Traffic Service
R&D	Research & Development
ARTCC	Air Route Traffic Control Center
HDDR	High Density Digital Recorder
EPIC	En Route Playback Interface Console
RIB	Record Interface Buffer
DCVG	Display Control & Vector Generator
DG	Display Generator
DGI/O	Display Generator Input/Output
PVD	Plan View Display (controllers display)
VAD	Valid Address
VCO	Voltage Controlled Oscillator
LPF	Low Pass Filter
D/A	Digital to Analog
SOD	Start of Display
EOD	End of Display
MUX	Multiplexer

BACKGROUND

Voice communication recordings have been employed for some time in the Air Traffic Control (ATC) system, and have proven to be a valuable tool in analyzing ATC events that have occurred in the system. As the current en route automation system has evolved, it has become evident that it would be useful to have additional recording of data within the automation system. At the present time much of the data contained in the automated system are being recorded via the System Analysis Recording (SAR) program. Although the statistical data collected by the SAR program are extensive, these recordings cannot be played back through a controller's display to provide a representation of data formatted in the same way that it had been displayed to a controller, including weather, display off-set, etc.

Development of a capability for recording of data in the en route display subsystem was requested by the Air Traffic Service (ATS) to enable them to re-create the data that had been presented to all en route controllers during their daily operations. A playback capability was also required so the recordings could be replayed to give a visual presentation of the air traffic situation as it appeared on a controller's display at any given instant. When combined with SAR data and voice recordings this would provide a more complete reconstruction of a given traffic situation. Some of the benefits that would be expected from this type of recording subsystem would be the ability to study and evaluate in detail air traffic conditions leading to ATC related situations. It could also be used as a maintenance tool to analyze reported discrepancies. Workloads and causes of traffic delays could be analyzed. Also, it could be used to aid in directing rescue operations.

In response to this request, SRDS began development in 1975 of a breadboard model to demonstrate feasibility of the display recording concept. The breadboard model was successfully demonstrated in May 1977. Based on the success of the breadboard model, a decision was made in June 1977, to proceed with the development of an Engineering Model to be designed and fabricated by in-house engineers. The functional requirements for the engineering model were completed in January 1978 and development of the engineering model was begun. The current schedule for the project is as follows:

Design Data	completed
Engineering Model Fabrication	3/80
Operational Demonstration	4/80
Test and Evaluation Completed	4/80
Technical Data Package To Airway Facilities Service	4/80

After the development is complete, it is expected that a production procurement will be initiated by the Airway Facility Service to install this type of display recording subsystem at all ARTCCs.

TECHNICAL APPROACH

a. Design Requirements

The following design requirements for the recorder were established as a result of coordination between the FAA Services.

1. Synchronize display recorder with voice recordings during playback.
2. High speed search of recorded tape in relation to a given time of day.
3. Simultaneous playback of two separate displays, without need for the ARTCC computer complex.
4. Duplicate the recorded tape for playback at other locations.
5. Record all data presented on the display.
6. Record all displays continuously in any ARTCC. (Engineering Model will record all displays at NAFEC.)
7. Freeze mode available during playback.
8. Monitor any on-line display while recording.
9. Transparent to existing automation and display equipment and operation.
10. Operate with any of the ARTCC display channel configurations.
11. Dual recorders will be required to operate in a sequential mode for continuous recordings.
12. Each recorder will operate a minimum of four hours on a single reel of tape.

b. General System Description

The engineering model is designed to meet the requirements for continuous recording of all displays interfaced with the en route display channel equipment and replay this data through the same type display from which the recordings were made. The subsystem has the following characteristics:

The display data from each display is sampled approximately once each second by a Record Interface Buffer (RIB) and is recorded on one of two High Density Digital (HDD) Recorders. These record data for 4 hours each in an alternating mode. Presentation of recorded data is accomplished by operating the recorders in a playback mode, through the En Route Playback Interface (EPI) to a standard display. A block diagram is shown in Figure 1.

The En Route displays are normally refreshed 55 times a second, and there is nominally one second between updates to the refresh data base. Most of the displayed data is redundant from a recording standpoint. Therefore, the design approach consists of storing on tape only one of the 55 identical display refresh frames which occur each second. The playback of the data requires a playback buffer EPI, a Display Control and Vector Generator (DCVG) and a display. A single refresh frame is transferred from tape to one of two semiconductor memories in the EPI. The frame stored in this memory is used to refresh a display at 55 frames per second. During this time, the next frame is transferred from tape to a second memory. Approximately every second, the two memories alternate between the modes of receiving data from tape and being used as a source of data for the display. This provides a playback presentation which is updated at the same rate as the original recorded data.

c. Record Function

1. DGI/O - DCVG Interface

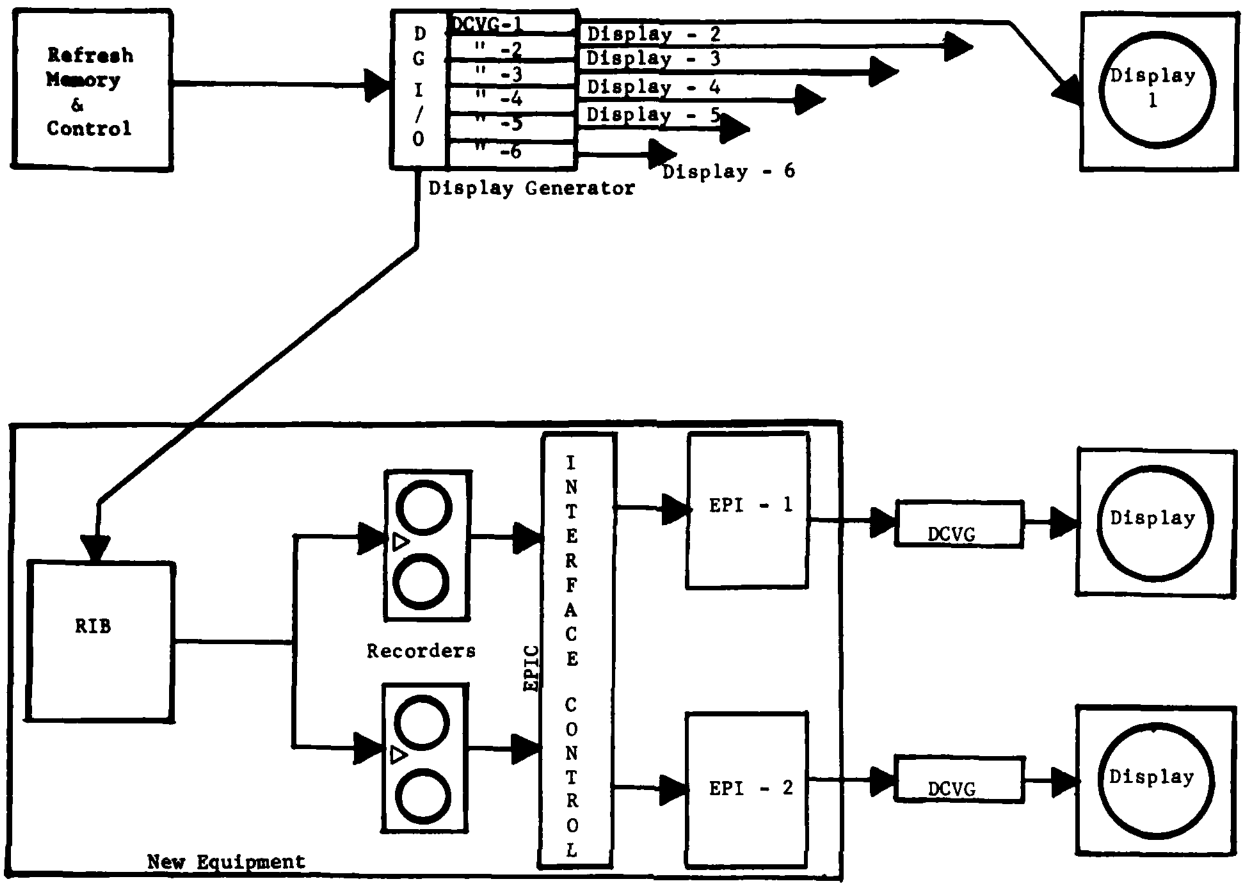

FIGURE 1, BLOCK DIAGRAM

Each Display Generator (DG) consists of a Display Generator Input/Output (DGI/O) assembly and six DCVGs. Each DCVG drives one display. The DGI/O contains data reclocking logic, a DCVG address decoder, a blink clock generator, and the DCVG output multiplexers. A 16-line parallel data bus from the DGI/O is common to all six DCVG drivers. Valid Address (VAD) signals sent to each DCVG indicates which data words a DCVG may receive. The DCVG input data word is a 64 bit word consisting of four 16-bit bytes which is received by the DCVG at a data rate of 4.444 megabytes per second. The RIB, Figure 2, will obtain the necessary data and control signals from this interface.

2. RIB Input

The RIB samples data for each of the six DCVGs in a cyclical sequence starting with DCVG-1. The sampling procedure consists of storing a single display refresh frame in the main memory of the RIB. The data stored in the memory is subsequently transferred to the recorder. When a complete frame has been sent to the recorder, the RIB goes on to sample the data from the next DCVG in the sequence. The sample interval is dependent upon the amount of data to be recorded.

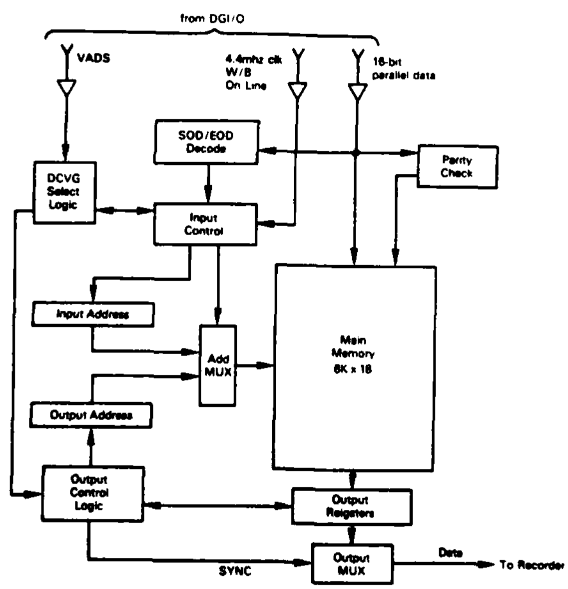

FIGURE 2, RECORD INTERFACE BUFFER (RIB) LOGIC

Preliminary experiments indicate that the average sample interval will be well under 1 second. Address bits in the sync words sent to the recorder indicate from which DCVG the data was taken.

The main memory operates on a first-in, first-out basis. The first data word written into memory is the first word out during the read sequence. In this manner, the DCVG data words of the sampled refresh frame are written on to tape in the same sequence as they were sent to the on-line DCVG and display. To accomplish this, two 13-stage binary address counters are used; one for the write address and the other for the read address. The appropriate counter is incremented for each byte written into or read out of memory. A multiplexer between the address counters and the memory, controlled by the input logic, determines which set of addresses are being used to access the memory. Both counters are reset prior to acquiring each refresh frame. Prior to reset, both counters are at the address of the last data byte.

3. RIB Output

The 64-bit DCVG data words, which are stored in the RIB memory as four 16-bit bytes, are turned 90 degrees by four parallel-in, serial-out registers called the output registers. The 90-degree terminology is used to designate the process of converting the DCVG data words from a 16-bit parallel, 4-byte serial format to a 4-byte parallel, 16-bit serial format. A 16-bit sync word is inserted between the data words sent to the recorder to enable the playback element to separate the data words and to provide display address information and parity information. These sync words are organized in four 4-bit bytes with each byte being recorded serially with a data byte on a separate track, Figure 3.

d. Playback Function

1. Equipment

The playback equipment consists of the following:

a. One High Density Digital Recorder (HDDR)
b. Two Off-line Plan View Displays (PVD)
c. Two En Route Playback Interfaces (EPI)
d. One En Route Playback Interface Console (EPIC)

There are two basic modes of operation for the playback element. The first is the playback mode in which the playback element is used to review or duplicate recorded tapes. The second is the monitor mode in which the playback element is used to visually monitor on a PVD the data as it is being recorded by the system. In the playback mode, it may be necessary to playback data from two displays simultaneously, as in the case of examining a hand-off situation.

An operator is able to control the operations of any recorder used in the playback mode. These operations include forward, fast forward, reverse, time code search, speed changes, and stop.

2. Time Synchronization of Recorders

Time synchronization of the digital recorders and the voice recorder on playback are accomplished using a time code reader (Figure 4) to decode time which is recorded on a single track on each tape. One recorder is used as a master unit with its speed controlled by its internal oscillator. All other recorders that are to be synchronized with this master unit are set to ignore their internal oscillators on playback and to use an external reference signal to control their speed.

3. Data Format

The EPI is designed to allow the operator to

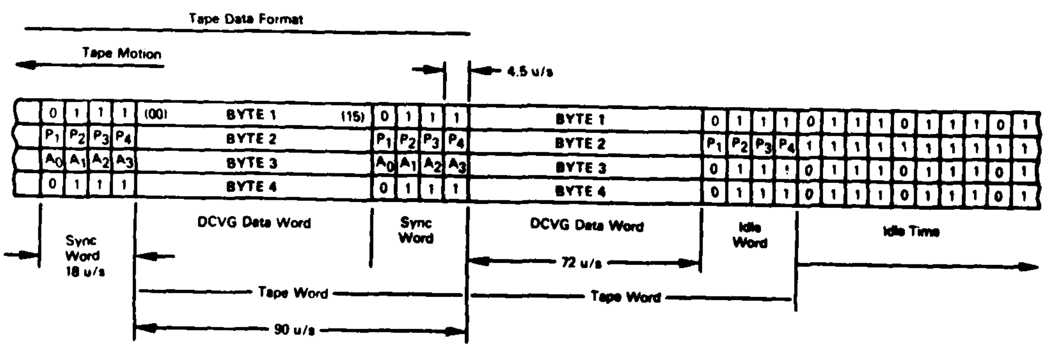

FIGURE 3, TAPE DATA FORMAT

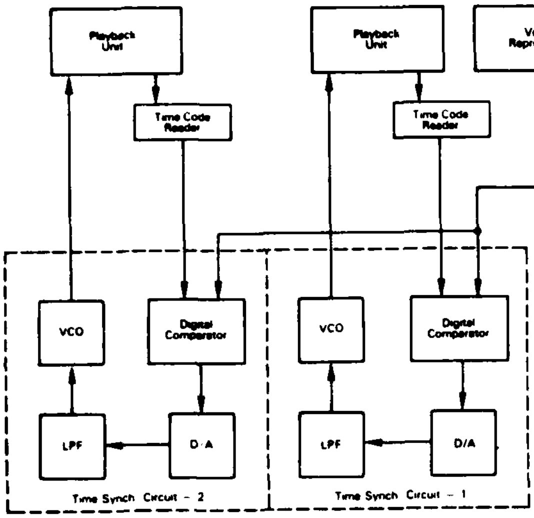

FIGURE 4, TIME CODE SYNCHRONIZATION LOGIC

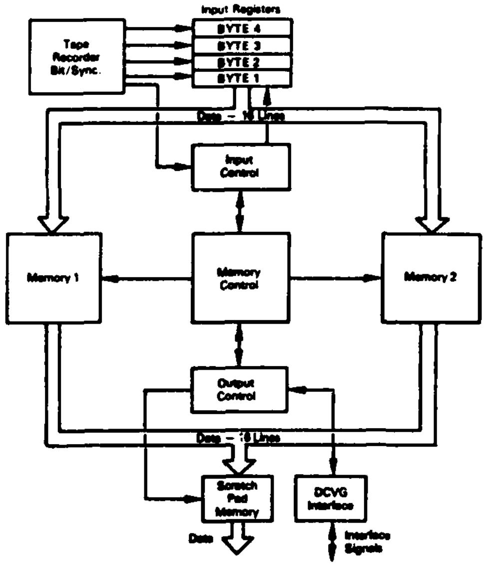

FIGURE 5, EN ROUTE PLAYBACK INTERFACE

designate the address of the display to be reviewed. The EPI compares the incoming address with the selected address and accept data only when the addresses are equal. This address information is used to designate one of the DCVGs within a DG. The DG is designated by selecting the proper port using the multiplexing scheme previously described. Each port corresponds to one DG.

The data received from tape by the EPI is stored in one of two semiconductor memories (Figure 5). When this memory has received a complete frame of data, the EPI uses the data to refresh the playback PVD via a DCVG. While the EPI is refreshing the display with data from the first memory (MI), it simultaneously stores the next frame of data from tape in the second memory (M2). When M2 has received a complete frame of data, the EPI switches over to M2 for refreshing the display, while it proceeds to load the next frame into M1. The EPI alternates between M1 and M2 in this manner as long as data is being received from the recorder or until operator intervention. A memory is considered full when it has received a complete frame of data, even though the memory may not be physically filled to capacity. The EPI alternates between memories (and between frames) at a rate which is equal to the sample rate used by the record element.

4. Playback Update Modes

The EPI is designed to operate in three modes: real-time, freeze, and twice-real-time. In the real-time mode, the playback tape speed is the same as the record tape speed, and the data is read from tape at the same rate at which it was recorded. Therefore, the playback display will be updated at the same rate as the data was sampled by the RIB. In the freeze mode the EPI continuously refreshes the display from a single memory without alternating. When the operator initiates the freeze mode, the EPI freezes the frame that is currently being used to refresh the display while it continues to load the other memory with the next frame sent by the recorder. Once an EPI is placed in the freeze mode, the operator may manually switch between the two memories and view each of the two frames stored for any length of time. When released from the freeze mode, the EPI switches to refresh the display from the alternate memory. It then proceeds to load the next frame of data coming from the recorder into the memory from which it has been refreshing prior to the release. In order to place the EPI at twice-real-time, the tape speed is changed to twice the speed of the real-time mode. At this speed the data is received by the EPI at twice the rate at which the data was sampled. When a speed change is made to place one EPI in the twice-real-time mode, the other EPI is automatically placed in the twice-real-time mode if it is receiving data from the same recorder.

SUMMARY

Recent developments in high speed memories and high density digital recorders have made practical the design of display recording systems. Design concepts were tested and proven through the fabrication and testing of a breadboard model, which though limited in capacity, used the same techniques being incorporated in the engineering model. Following evaluation of the engineering model, procurement specifications will be written and production recording systems will be procured for installation at all en route centers. With the installation of this equipment the FAA will be in a better position to analyze and document various events occurring in the en route air traffic control system.

The author would like to acknowledge the design efforts of Mr. Edwin A. Mack and Stephen D. Stratoti, ANA-140, who designed the breadboard model and provided much of the data contained in this report.

A NEW AIRPORT SURFACE DETECTION EQUIPMENT SURVEILLANCE RADAR

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BIOGRAPHY

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Mr. Bloom received his degree in Electronic Engineering from Manhattan College in 1957 and has completed graduate studies at the University of Florida. He was a Field Service Engineer at Sevromechanisms, Inc., in 1951. Subsequently, he worked on the electronic design of a missile guidance system at Honeywell Aero, Florida. He also worked at Dynamics Research Corporation on minicomputers and digital technology systems development. He has been at TSC since 1971 and is a Project Engineer for the ASDE-3 radar.

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Mr. O'Grady is a 1957 graduate of Annapolis and received his Masters Degree from Stanford University in 1963. He worked on missile and airborne systems development with the Air Force Systems Command from 1957-1967. He is currently employed with the Transportation Systems Center in Cambridge, Massachusetts where he is Chief of the Airport Systems Branch.

ABSTRACT

The key factor necessary for Airport Surface Traffic Control is adequate surveillance capability for the Control Tower under all operating weather conditions. ASDE is the solution for providing the surveillance capability under poor visibility conditions at most airports when the primary visual surveillance mode through the Control Tower's windows cannot be used. A new airport surface surveillance radar, ASDE-3, is currently being developed by the Federal Aviation Administration (FAA) to satisfy the Control Tower requirements.

The paper develops the critical surveillance and design requirements that the new ASDE-3 radar has to meet.

ASDE DESIGN CONSIDERATIONS

Weather Penetration, a Primary Requirement

The role of an ASDE is to provide the alternative means of airport surveillance for the Control Tower when visibility through the tower windows is restricted. The most persistent complaint of Controllers regarding the present ASDE-2 has been that it works best when they do not need it, and works worst when they need it the most. Since visibility restrictions are caused by weather, weather penetration is a primary ASDE requirement. The ASDE-3 weather penetration (rainfall rate) requirement is based on several factors including climatic data for candidate airports, visibility effects of weather, the operational availability needed for reliable surveillance, and the performance which can reasonably be achieved by an ASDE radar.

Over 30 airports have been identified as ASDE-3 candidates using the FAA ASDE establishment criteria. Available climatic data for 21 airports slated to receive ASDE-3 were analyzed to determine the rainfall rate capability required at each airport to assure ASDE surveillance availability for the Control Tower 85 percent of the time when visibility is under 1 mile.

Fig. 1. shows the rainfall rate capability required for each site plotted against the maximum range required at each site. The data plotted establish the limits of weather penetration required for ASDE-3 as a function of range. Also plotted on the same figure is the result of a radar detection analysis of a 16 GHz ASDE-3 using reasonable and achievable parameters. A constant-detection criterion was assumed, using a probability of

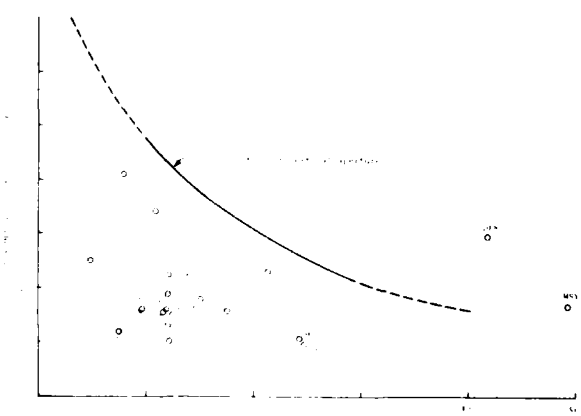

Figure 1

Rainfall rate requirement
for 21 U.S. airports

detection (P_d) of 0.9 and a probability of false alarm (P_{fa}) of 10^{-6} for a non-fluctuating $3m^2$ target, without integration. Note that the ASDE-3 radar as plotted satisfies all sites except 2; i.e., Dallas Fort Worth (DFW) and New Orleans (MSY), which would be satisfied if 90 instead of 95 percent availability were used. Thus, an ASDE-3 radar with characteristics similar to those assumed adequately satisfies the weather penetration requirements.

Achieving weather penetration is an important ASDE design consideration; however, equally important is the presentation of a good surveillance picture on the Control Tower display.

Providing the Surveillance Information on the ASDE Control Tower Display

The Control Tower, to perform its traffic management functions, requires the ASDE display to provide target-imaging and target-to-target resolution to:

a. Discern any active runway traffic.

b. Discern the position of aircraft/vehicle relative to runway and taxiway intersections.

c. Track traffic on runways and taxiways, and discriminate closely spaced targets.

d. Recognize aircraft by shape and size.

e. Recognize airport runway and taxiway background.

These functions require a radar resolution about 15 to 20 feet in range and 0.25 degree in azimuth, and an antenna rotation rate of once per second. The rotation rate is based on long experience with ASDE-2, and on simulation studies done by the Transportation Systems Center (TSC).[2]

The ASDE-3 will use the ASDE NUBRITE display system developed by TSC for FAA and built by ITT, Fort Wayne. This TV-vidicon scan-conversion display system, based on the Airport Surveillance Radar (ASR) BRITE technology, was specifically developed for the ASDE application, and is currently installed and successfully operating at three ASDE-2 sites. The NUBRITE uses a high-brightness, high-contrast TV compatible with Control Tower ambient light conditions, and has a 15-foot resolution capability on the 6000 feet per diameter scale.

Another important factor related to the presentation of surface surveillance information to the Control Tower is the ability of the display to allow the controller quickly to acquire and track targets of interest. ASDE radar returns provide near photographic-quality data from the entire airport surface display, including grass areas, buildings, and other surface features outside of the traffic movement areas of interest. Displaying extraneous information from outside of the taxiway/runway movement areas limits the ability of the display to present clearly the surveillance information normally needed. (Surveillance of other parts of the airport outside of the movement areas may be necessary under certain emergency conditions.) To provide the best possible presentation of the taxiway/runway movement areas, ASDE-3 will include a unit similar to a mapper, calleld a Display Enhancement Unit (DEU). The DEU, as illustrated in Fig. 2, allows the controller proportionally to adjust the contrast between movement and non-movement areas, and also the intensity of map lines defining the movement areas.

Experiments conducted by TSC at Dallas, Love Field, Texas, using a DEU breadboard developed by Texas Instruments, indicated a 25 to 40 percent improvement in "quick look" aircraft-detection capability when compared with a normal ASDE presentation.

Airport Site Factors

Since the ASDE is to provide surface surveillance for the Tower Controllers, the radar must be located in a position providing line-of-sight to all parts of the airport surface. For most airports, the ideal location would be the Control Tower roof. However, at many airports, the Control Tower structure is very limited in the ability to support additional loads on the roof. Consequently, the weight and size of the ASDE-3 antenna/radome assembly should be as small as possible for the radar to be compatible with as many Towers as possible. Considering Control Tower roof dimensions, the horizontal extent of the ASDE-3 antenna/radome is limited to 18 feet.

If because of structural problems or siting considerations the antenna cannot be located on the Control Tower, the ASDE-3 must be able to be configured to allow remoting from a separate ASDE tower to the Control Tower. A review of potential remote tower sites indicates a remoting distance of 8000 feet is needed.

The range-coverage requirements for the ASDE-3 are also dictated by the needs of the candidate airports. Coverage is required from a minimum range of 500 feet to a maximum range of 18,000 feet to satisfy all airports, with the antenna mounted on towers ranging from 40 to 300 feet in height.

ASDE-3 DESIGN SUMMARY

In the process of transforming ASTC operational requirements into equipment design requirements, several tradeoff areas were considered. The chosen design approach represents the maximum weather penetration performance possible for a given antenna enclosure size constrained by wind-induced overturning movement considerations. The most interesting features of the resulting design are the integral antenna/rotodome, antenna variable focus, cosecant (CSC) elevation beam-shaping, and pulse-to-pulse frequency agility.

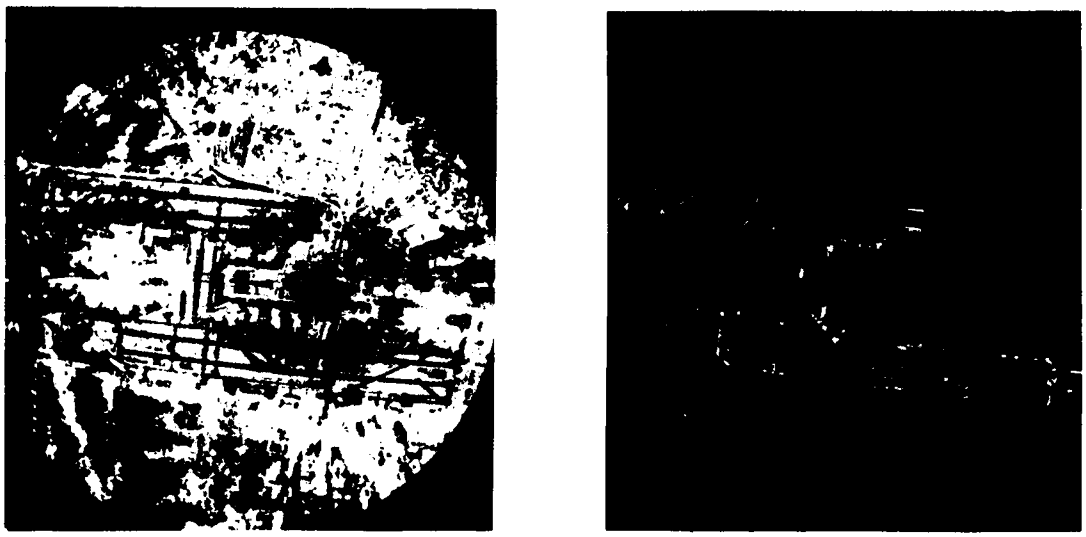

Figure 2

Los Angeles Airport ASDE without and with a Display Enhancement Unit (DEU)

The engineering model ASDE-3 consists of the radar transmitter/receiver and its associated electronics, the antenna/rotodome, the DEU and a test data acquisition system (DAS). The DEU-gated video output interfaces with the NUBRITE video-scan-converted tower cab display (Fig. 3).

The Antenna, Determinant of System Performance

The antenna is the most critical determinant of system performance. It is the predominant factor in the detection of signals in precipitation clutter and noise and in establishing azimuth resolution. Gain, azimuth beamwidth, and elevation beam-shape optimization are limited by the 18-foot rooftop maximum horizontal dimension. The design takes advantage of the lower rainfall attenuation and backscatter coefficients at 16 GHz (compared with the 24 GHz which was used for ASDE-2), and achieves maximum packaging efficiency by using an integral antenna/radome (or rotodome) shown in Figures 4a and 4b.

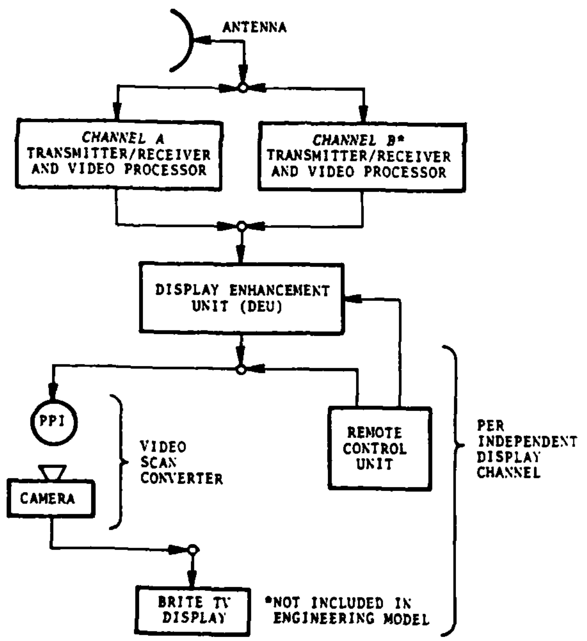

Figure 3

ASDE-3 block diagram

The choice of the 16 GHz band* was based on a comparison of signal-to-noise-plus-clutter performance in heavy rainfall for 16 and 24 GHz. This

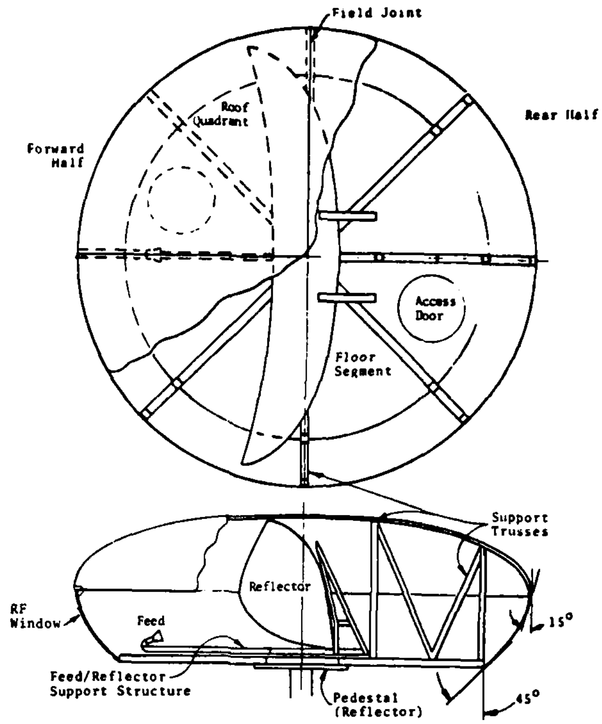

Figure 4a

Rotodome configuration

comparison showed the lower frequency band clearly superior even for equal physical antenna sizes.

Frequency selection. The radar precipitation backscatter coefficient at 24 GHz, the current ASDE-2 assignment, is considerably greater than the value at 16 GHz for heavy rainfall (about 7 db greater for a 16 mm/hr rainfall rate).[3] Two-way attenuation in heavy rainfall is over 6 db greater per nautical mile at 24 GHz.[3,4,5] Sixteen GHz also has the benefit of considerably reduced RF attenuation through water film on the radome exterior. The increased antenna performance at 24 GHz, both in gain and in precipitation clutter cell reduction, is more than offset by the reduced rainfall attentuation and backscatter cross section at 16 GHz.

Integral Rotodome. An overall system azimuth resolution of 40 feet for targets at 6000 feet in range is required to prevent smearing of extended targets and to resolve small point targets on the airport surface. To resolve 40 feet on the NUBRITE display requires an antenna 3 db azimuth beamwidth of 0.25 degree.* The resulting

*Actual assignment received for development work is 15.7 to 16.2 GHz.

*The convolution of the effective azimuth beamwidth at 6000 feet (26 feet) and the display response (30 feet) gives 40 feet.

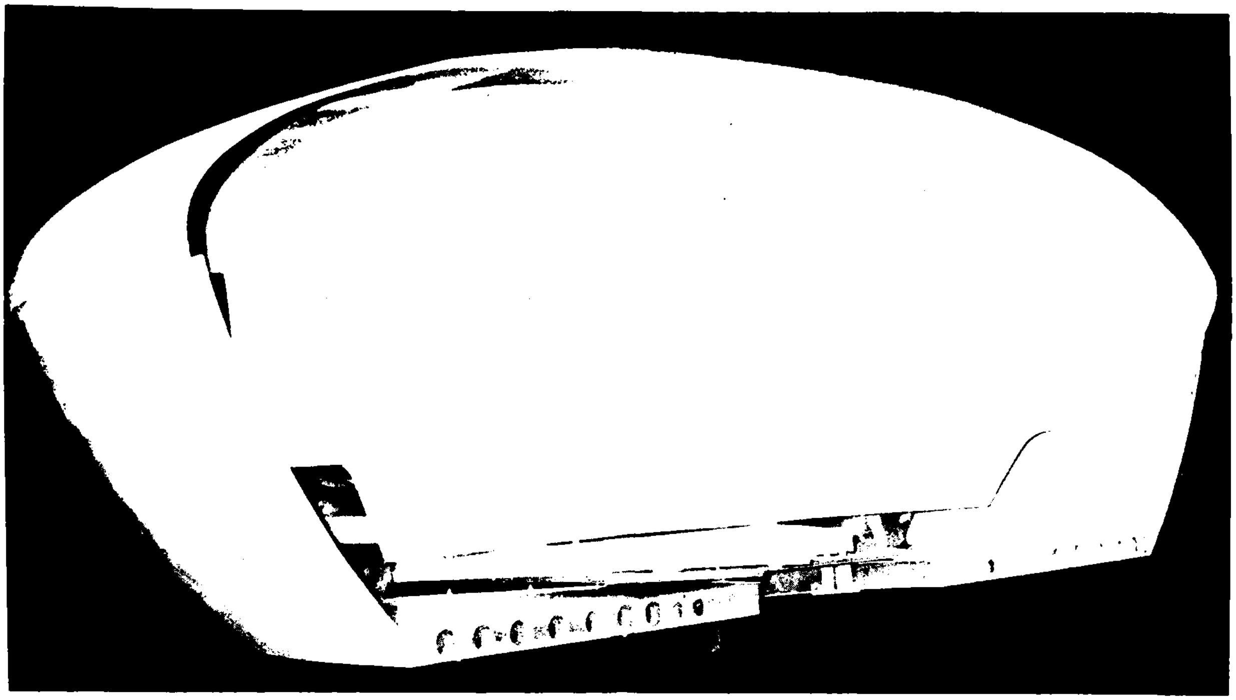

Figure 4b Rotodome Configuration (Actual cutaway photograph)

horizontal aperture giving a 0.25 degree 3 db beamwidth at 16 GHz is 17 feet, nearly the 18-foot maximum set for the horizontal rooftop dimension. A 17-foot rotating antenna enclosed in a stationary 18-foot radome would result in (1) excessive shear forces due to the proximity of the antenna tips to the fixed radome, and (2) variations of radome RF transmission characteristics with antenna rotation. The first problem greatly increased drive horsepower and antenna stiffness requirements, and therefore weight and size. The second problem is particularly critical as the angles of incidence through the radome are very non-uniform across the aperture; i.e., considerable radome curvature near the reflector edges. An integral radome (or rotodome) allows more care in the control of an RF window which maintains a constant relationship to the antenna with rotation. Beside making the maximum use of the available enclosure dimensions and optimizing the RF window performance, the rotodome also has a rainshedding advantage. The centrifugal force prevents the formation of a highly attenuating thin film of water over the RF window.

Because of these considerations, the rotodome design is being used for ASDE-3 (Fig. 4a). The shape of the rotodome is a modified ellipsoid, an optimum shape to reduce aerodynamic drag and overturning moment. Comparing the ellipsoid with a spherical radome of the same diameter indicates a 2:1 improvement in overturning moment when measured on a ground plane.

Vertical aperture size and cosecant elevation beamshape. Once the horizontal aperture was established at 17 feet, the vertical aperture was dictated by the required peak gain and vertical directivity set by the system rainfall-performance requirements. The approximate 5-foot vertical aperture of the chosen design provides a 1.6 degree elevation beamwidth (at the 3db points), maintaining the aspect ratio below 4:1 held critical for a point-source fed reflector.* The resulting peak gain of 45 dbi provides the basis for the 3 mile performance capability of ASDE-3.

The elevation beamshape optimizes the tradeoff between peak gain on elevation boresight (affecting target returns at maximum range) and gain at high-depression angles (corresponding to targets at close range). In clear weather, receiver noise is the limiting factor in detection. A perfect CSC-squared elevation pattern exactly compensates for the fourth-power range dependence of a surface-target return. Because noise is constant with range, the CSC-squared pattern gives a constant signal-to-noise ratio.

Precipitation clutter returns, however, are range-dependent in the same fashion as

*Beyond that aspect ratio, a line-source feed-cylindrical reflector design must be considered, with attendant problems in obtaining adequate dynamic beamshape, weight, and cost.

the target (Fig. 5a). The use of a cosecant-squared pattern in heavy rainfall results in severely diminishing the signal-to-clutter ratio at close range (Fig. 5b) because the clutter power, contributed largely from the elevation boresight region, is increasing (lower solid line on Fig. 5a) while signal power is constant (upper solid line on Fig. 5a). By comparison, the cosecant pattern maintains a relatively constant signal-to-clutter ratio for the ranges of interest. The elevation beamshape chosen for ASDE-3 is CSC for depression angles from -4 to -31 degrees, achieving the desired S/N+C effect, and is shaped CSC to the 1.5 power from -4 to -1.6 degrees for slightly increased gain. Coverage to a 31 degree depression angle accommodates a minimum range of 500 feet for the tallest control tower.

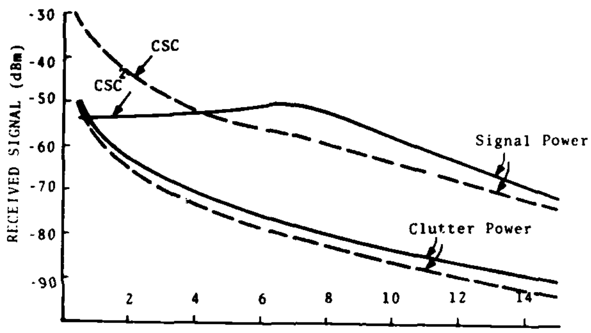

Figure 5a

Signal, clutter and range for cosecant and cosecant-squared beamshapes

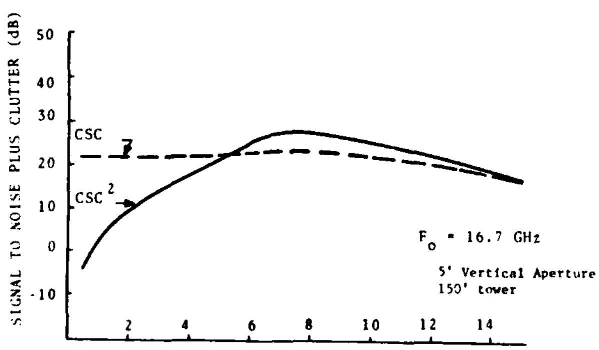

Figure 5b

ASDE signal-to-noise-plus clutter performance: cosecant and cosecant-squared elevation beamshapes

The approach used for the ASDE-3 system is a variable focus antenna whose reflector consists of a series of elliptical horizontal contours whose eccentricity varies with depression angle. (See Fig. 6). In this technique, the feed horn is located at the primary foci of these ellipses. The major axes are the slant ranges from the tower so that the conjugate foci, as illustrated by F_1, F_2, and F_3, lie on the runway surface. In this manner, the spot size remains essentially constant with surface range.

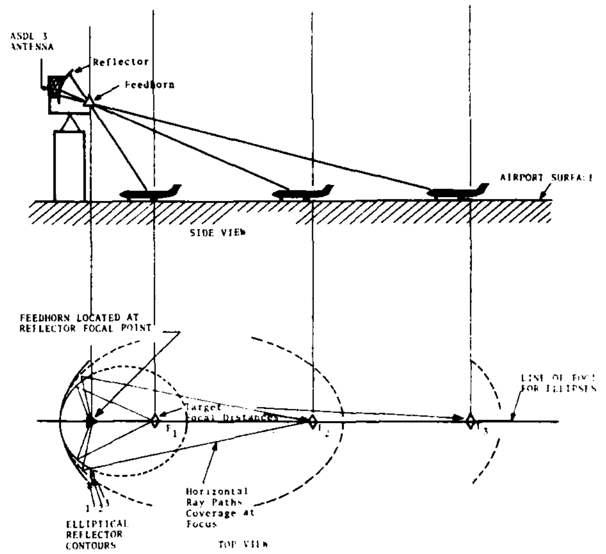

Figure 6

ASDE-3 antenna focus variation as a function of target range

Improvement in signal-to-noise plus clutter is expected from the variable-focus feature since the target on the airport surface will always be in focus while the clutter volume, which extends up from the surface, will be defocused because it is a different elevation angle for that range cell. Defocusing the clutter volume reduces the net backscatter as follows. For ranges within the 4900-foot near-field point, the azimuth clutter cell becomes constant at the horizontal aperture width, having the same effect as incresing the clutter echo power by an inverse-range factor relative to the converging azimuth beam far-field case. The antenna gain in the defocused boresight region decreases commensurate with the azimuth beam-broadening. Because the square of the gain function appears in the radar equation, the net-gain dependence is proportional to the square of range. The combined effect results in an added range dependence in the numerator of the clutter power term, causing the signal-to-clutter ratio to be better by 3 db per octave for decreasing range than the case where clutter and target are both in the far field.

Frequency Agile Transmitter/Receiver

Another significant departure of the ASDE-3 from its predecessors is the use of a multiple-step frequency-agile traveling wave tube (TWT) transmitter. Benefits from frequency agility are expected in three areas; (a) precipitation-clutter pulse-to-pulse decorrelation, (b) improvement in target-imaging, and (c) elimination of multiple-time-around targets.

Display Enhancement Unit

An all-digital DEU is part of the ASDE-3 engineering model. In addition to providing the digitally generated map of the airport, and separating areas of interest from suppressed areas (Fig. 2) the DEU provides adaptive receiver-gain control, frequency-agile control, and test-data-collection control functions for the radar system.

The DEU takes rho-theta analog radar video and mixes it with map data in real time, outputting the mixed video to the NUBRITE display system. Map information is stored in and read out of a random access memory (RAM) by radar range and azimuth. Depending upon the setting of an enhance/suppress bit in each accessed memory location, the DEU output is either enabled for critical airport areas or variably suppressed for background areas. The intensity of map lines, background airport-surface feature video, and critical area video are all independently controlled from the tower-cab display-control head.

The creation of the DEU map information is accomplished at the airport site by an interactive process utilizing software residing in the desk top controller. The map data are stored on magnetic tape, automatically loading into the DEU RAM at power up. Range information is quantized into 2048 cells (11 bits giving an 8.8-foot range cell for an 18,000-foot radius. Azimuth is quantized to 8192 values (13 bits), resulting in an azimuth cell of 14 feet at 18,000-foot range. Map line-width variation is held to 22.5 $\pm$ 7.5 feet (15 to 30 feet). Hardware (clock stability and synchronization, and azimuth pulse generator stability) and software (algorithm for data compression) errors and range/azimuth precision are budgeted such that positioning of the map line and boundary relative to the critical area can be maintained between 0 and 30 feet. A line-segment computation algorithm is used to eliminate the brute-force storage of every quantized-line segment, reducing memory requirements from 160,000 to 8,000 words (20:1).

Schedule

The ASDE-3 contract was awarded in May 1977. Test and evaluation at NAFEC is scheduled to be completed in early CY-1980. This schedule supports an FY-81 production procurement.

Conclusion

The ASDE-3 will provide a significant improvement over the ASDE-2. Aside from advances in the state-of-the-art, the improvements are primarily attributable to the use of a lower frequency (16 vs. 24 GH_z) and a unique antenna design coupled with the use of frequency agility.

A concern for properly documented user requirements and a top-down systems approach have dominated the selection of ASDE-3 parameters. Parameter optimization against requirements has been central to the design process. The results will be a radar which, while representing a major improvement over the best equipment now available, avoids advanced technologies which were not necessary to meet system needs.

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The ASDE-3 radar is being built by Cardion Electronics, a unit of General Signal Corporation, Woodbury, NY, 11797.

DIGITAL RADAR REMOTING FOR AIR TRAFFIC CONTROL TERMINAL AREAS

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BIOGRAPHY

John D. Horrocks is a Project Engineer in the Systems Research and Development Service, ATC Automation Division. He received his B.S. in Electrical Engineering in 1968 from the University of Maryland. He has worked in the Terminal Automation Program since 1969 where he has been responsible for the development of enhanced ARTS-III hardware and software systems.

Abstract

The Tampa/Sarasota Remote Radar Processing Program is an extension to the ARTS-IIIA ATC system that will increase safety and reduce controller workloads at satellite airports. Through the use of state-of-the-art radar digitizers, radar data from remotely located radars is transmitted over telephone lines to a central ARTS-IIIA facility. The radar data is processed and distributed to the TRACON and to all towers under the coverage of one of the facility's radars for display in the tower cab on new high contrast digital displays. The benefits of this system will be the availability of radar and automation services at airports without an on-site radar and better coordination between the TRACON and all towers within the coverage of the radars.

Introduction

As computer and radar technology has become more sophisticated, the ATC Automation Division has continued to seek ways to increase ATC safety and to economically expand service to smaller airports. The Tampa/Sarasota Radar Remoting project, now commissioned and undergoing evaluation, has accomplished both these goals.

Radar data from both the Tampa and Sarasota radars, which are separated by 35 miles, is first digitized by the Sensor Receiver and Processor (SRAP) and transmitted to the Tampa TRACON over telephone lines. The ARTS-IIIA Data Processing System (DPS) at Tampa receives this radar data, tracks it, and distributes it to displays in the Tampa TRACON for Arrival/Departure control of the entire Tampa and

Sarasota airspace. The Tampa TRACON contains displays for both the Tampa and Sarasota radars. The Tampa displays are standard ARTS-III DEDS displays which receive and display analog broadband video from the Tampa radar. The Sarasota displays in the Tampa TRACON are all-digital displays that receive and display digital data from the Sarasota radar which has been processed through the Tampa DPS. The tracking data is also distributed to the Remote Display Buffer Memories (RDBM) located in tower cabs at Tampa, Sarasota, St. Petersburg, and MacDill AFB, for display on the Tower Cab Digital Displays (TCDD).

The expected benefits of this system are:

1. Economical methods for providing expanded radar and automation service to the satellite airports within the coverage of the Tampa and Sarasota radars.

2. Enhanced safety and reduced controller workload due to the ease of coordinating traffic flow between the Tampa TRACON and the satellite towers.

This paper presents a summary review of the system design, a description of the system test program and a summary of the system modifications necessary before commissioning could take place.

<u>ARTS IIIA Radar Remoting System</u> - The ARTS-IIIA Radar Remoting System is an ARTS-IIIA system with the addition of radar remoting and remote display capabilities. In addition to the standard ARTS-IIIA systems, remoting requires: a Communications Multiplexer Controller (CMC) to interface the data circuits with the ARTS-IIIA Input/Output Processors (IOP), Sensor Receiver and Processors (SRAP) to digitize the primary and secondary radar videos, Tower Cab Digital Displays (TCDD) and Remote Display Buffer Memories (RDBM). The RDBM receives the digital display data from the host ARTS-IIIA system, stores the data and refreshes the TCDD. Figure 1

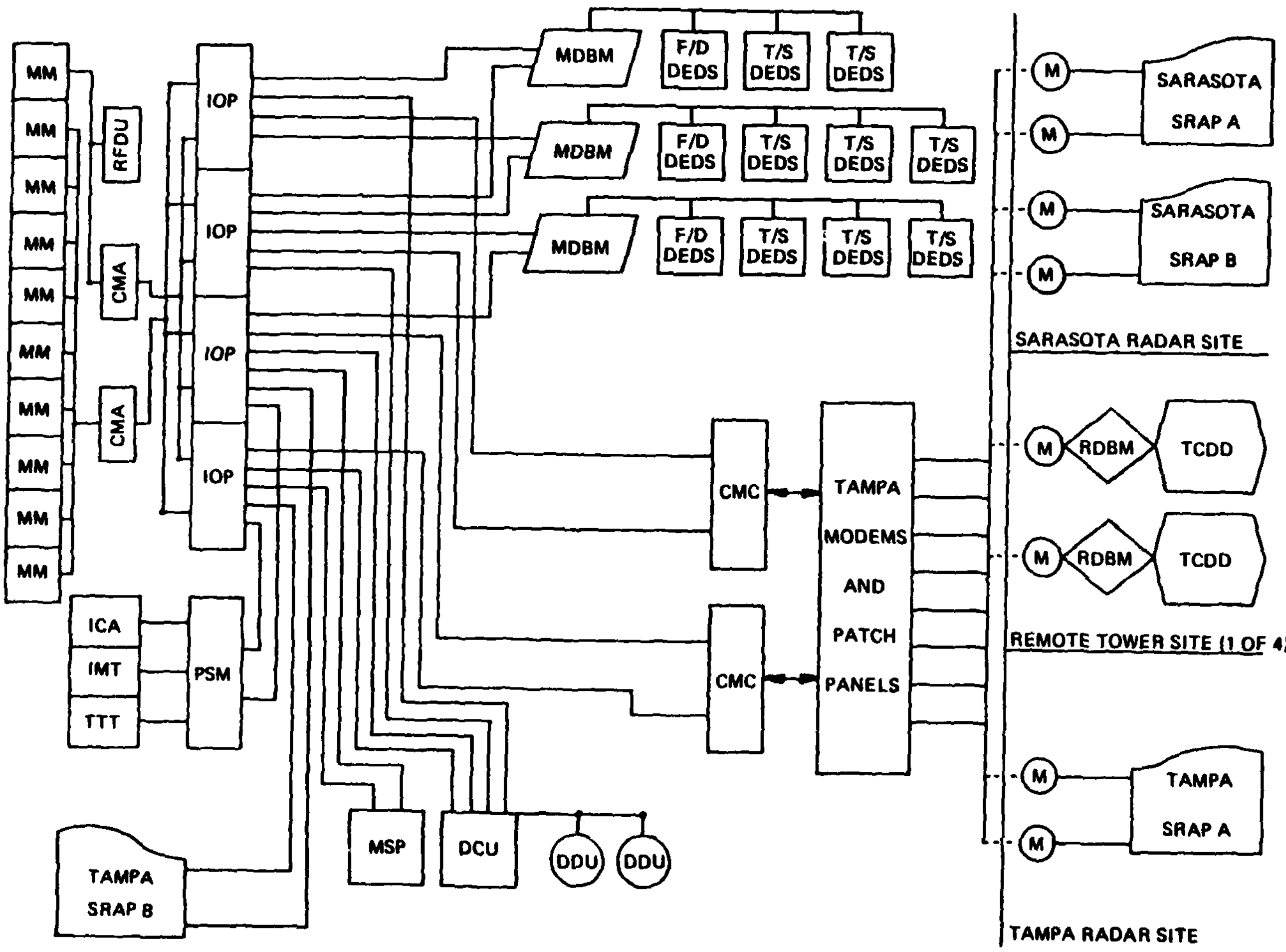

Figure 1. ARTS-IIIA Radar Remoting System Block Diagram.

is a block diagram of the ARTS-IIIA remoting system. Table 1 identifies all the abbreviations used on the block diagram.

Table I ABBREVIATIONS

MM -	16K (30 bit word) Memory Module
CMA -	Central Memory Access, a buffer driver between the IOPs and memories
RFDU -	Reconfiguration Fault Detection Unit, provides for automatic and manual partitioning of memories and processors
IOP -	Input/Output Processor, main computing element for the ARTS-IIIA
ICA -	Interfacility Communications Adapter for 2400 bit/second communications link to air route traffic control center
IMT -	Integral Magnetic Tape Adapter for 7 track Potter tape drive
TTT -	Teletype adapter for ASR-37 console typewriter
PSM -	Peripheral Switch Module provides for switching ICA, IMT and TTY between two IOPs
MDBM -	Multiplexed Display Buffer Memory provides display refresh memory for the DEDS
F/D DEDS	- Full Digital Data Entry Display subsystem, keyboard and full digital display for ATC controller use
T/S DEDS	- Time shared DEDS, keyboard and dual mode display for ATC controller use (broadband video and alphanumerics during radar dead time)
BANS -	Brite Alphanumeric System, A TV mode display bright enough for tower cab use and has full alphanumeric capability with keyboard
CMC -	Communications Multiplexer Controller, provides modem link interface for up to 16 full duplex devices with speeds up to 9600 bits/second
SRAPA -	Sensor Receiver and Processor Adapter interfaces the modems to the CMC for receipt of data in SRAP format
CIDIN -	Common ICAO Data Interchange Network is the international standard data communications protocol for ATC systems
CTA/CRA -	Communications Transmit Adapter/Communications Receive Adapter, interfaces the modems to the CMC or RDBM for transmission and reception of digital data over telephone lines
MSP -	Medium Speed Printer, a 300 line per minute printer
DCU -	Disc Control Unit controls up to 16 disc drives
DDU -	Disc Drive Unit, a 100 Megabyte per disc pack unit that will be used to store recovery module, backup program library, on call programs, critical data and continuous data for ATC history
RDBM -	Remote Display Buffer Memory, a remote interface unit between the IOP and TCDD. Refreshes the TCDD and formats keyboard messages for return to the IOP
TCDD -	Tower Cab Digital Display, a bright full digital display for tower cab use
SRAP -	Sensor Receiver and Processor, a primary and secondary radar digitizer and target detection unit

Five of the hardware devices used in the ARTS-IIIA Radar Remoting system are somewhat unique. They include the SRAP, RDBM, TCDD, MDBM and CMC. A brief summary of their main characteristics follows:

Sensor Receiver and Processor (SRAP) - The SRAP is comprised of three distinct units, the Radar Data Acquisition Subsystem (RDAS), the Beacon Data Acquisition Subsystem (BDAS) and the Common Processing Subsystem (CPS). Figure 2 illustrates the system configuration.

The function of the RDAS is to detect and transfer aircraft target and weather data derived from search radar video returns. The BDAS provides detection and transfer of aircraft target data derived from beacon transponder replies. The CPS provides, target quality filtering, radar only threshold control, correlation and merging of radar and beacon target reports and outputs target and weather data to the IOP or modems.

Communications Multiplexer Controller (CMC) - The CMC is a communications front end processor designed to simplify the job of interfacing a variety of different communication channels to the ARTS-IIIA DPS. The CMC can multiplex any combination of up to 32 plug-in simplex transmit or receive peripheral interface adapters with either of two ARTS-III Input/Output Processors (IOPs). The

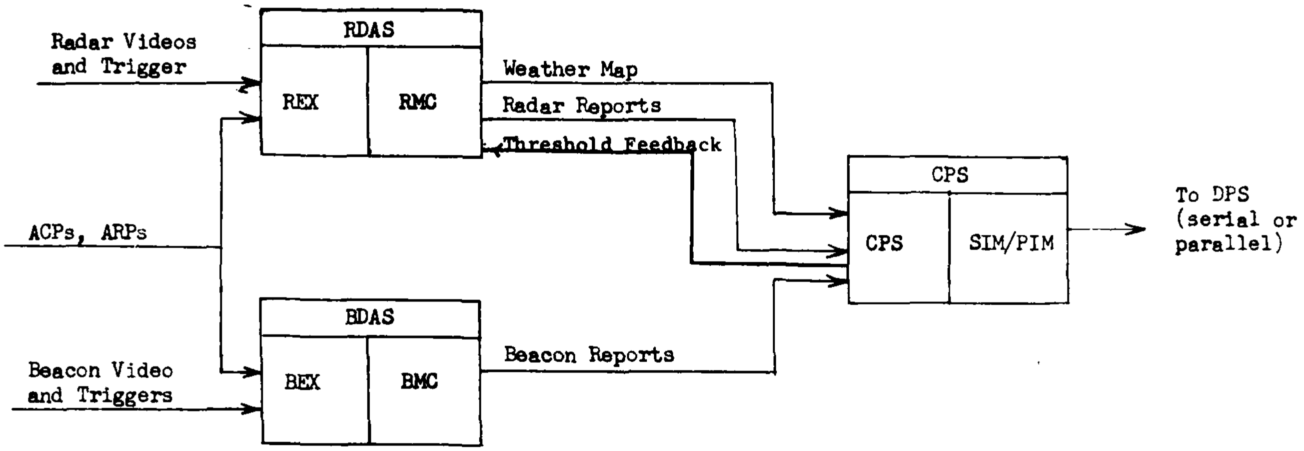

Figure 2. SRAP System Configuration

CMC consists of a multiplexer, standardized plug-in facilities to accommodate a variety of interface adapters, and a self-contained power supply. Maintenance is simplified by the inclusion of built-in diagnostics.

Two interface adapters are currently used in the CMC. The SRAPA for simplex serial operation, up to 9600 bps is used to receive SRAP data. The CTA/CRA adapter is used for full duplex communication, up to 9600 bps, with the RDBM. It provides complete error control using the FAA standard CIDIN communications protocol.

Multiplexed Display Buffer Memory (MDBM) - The MDBM functions in either the time shared or all digital ATC system by receiving lists of display commands from one of two processor output channels, storing them for sequential read out to a display, or for the readback of data to the processor input channel upon request.

The MDBM enables the display to continue to present alphanumerics data to the DEDS in event of a primary processor failure. Thus, the visual information available to the controller at the time of the failure is not lost during either manual or automatic reconfiguration and restart of the system.

Remote Display Buffer Memory (RDBM) - The RDBM provides the interface between the TCDD and the ARTS IIIA DPS via telephone data communication circuits. The RDBM is a firmware controlled device which receives display commands and ATC data from the ARTS-IIIA DPS and refreshes the TCDD. The RDBM also processes local keyboard and trackball data and formats it for transmission to the DPS. A sophisticated error control procedure using the CMC type CIDIN Protocol assures correctness of diplayed ATC data. For ease of maintenance, the RDBM has built in diagnostics both for itself and the TCDD.

Tower Cab Digital Display (TCDD) - The TCDD is a computer driven, all digital display subsystem incorporating all elements necessary for stand alone operation in tower cab environment. It features a random positioned, high speed display monitor that produces high brightness imagery of both alphanumeric and graphical data. The data presented consists of digitized radar, data blocks, tabular lists, range rings, maps and weather. A full complement of data entry devices, including two keyboard and trackball modules and one control panel is included, permitting easy operator interaction with the ARTS-IIIA DPS.

System Reliability and Maintainability - The reliability and maintainability of the basic ARTS-III equipments has been demonstrated in several tests and extensive field experiences. The ARTS-IIIA remoting system makes use of both proven ARTS-III equipments and new system components. The new devices basically include the SRAP, RDBM, TCDD and CMC modules. These devices have had their designs influenced greatly by reliability and maintainability considerations. The SRAP, RDBM and CMC employ microprocessors in their design and built-in test hardware and software. The Mean Time To Repair (MTTR) goals for each of these devices is 10 minutes. The SRAP, CMC, Modems, and Phone Lines make up the radar remoting link to Sarasota. Since dual SRAP units are provided and the Modem/Phone Line problems can be quickly isolated through the use of patch panels, fault isolation to a specific element should be fast and definite. The same basic redundancy exists at the remote tower sites with dual phone lines, modems, RDBMs and TCDDs. This, in conjunction with the excellent MTTRs of the individual system elements and system redundancy, should provide excellent system maintainability equal to or better than the basic ARTS-III system.

System Software - The system software consists of four distinct types: 1) Operational, 2) On-Call, 3) Off-Line, and 4) Recovery. The Operational Software consists of 1) Executive, 2) Task Elements, and 3) Data Base Elements. All portions of the Operational Software will be resident in computer memory. The operational software is responsible for providing the real-time ATC functions of the system. The On-Call Software consists of software tasks or modules which will be loaded from the disc into an area of operational computer memory reserved for this purpose. The On-Call capability is used for modules which require use of operational peripherals or access to the operational program but are not required as part of the operational program.

Off-Line Software is the collection of support, utility, and diagnostic software which operates independently of the operational program, except that the off-line and operational program will share the disc subsystem.

Recovery Software is executed following a scatter interrupt which may be initiated manually at the Reconfiguration and Fault Detection Unit (RFDU) or automatically after a failure within the computer system. Recovery software consists of two parts, 1) Non Destructive Read Only Memory (NDRO), and 2) Recovery Module. The NDRO module is contained in read only memory within each processor. The NDRO module will determine the initial processor and memory resources and load the recovery module from disc to the lowest operational numbered original memory unit. The recovery module consists of processor and memory diagnostics. These diagnostics refine the list of initial resources. After final evaluation is complete, the recovery module loads the operational program consistent with the available resources, loads the last good recorded data base and restarts.

Operational Software - The software function is divided into eight major areas:

1. Multiprocessing Executive (MPE)
2. SRAP Input Processing (Local and Remote)
3. Tracking
4. Display Output Processing (including Remote TCDD)
5. Keyboard Input Processing (including Remote TCDD)
6. Interfacility Flight Plan Processing
7. Minimum Safe Altitude Warning (MSAW)
8. Continuous Data Recording

The MPE provides overall control of the system resources for efficient ATC operational program execution.

The SRAP Input processing accepts declared targets and passes them to tracking.

The tracking function performs a scan-to-scan correlation of the declared targets to provide positional and informational data for display output processing. The positional data is the XY Position in radar coordinates. The informational data is the ground speed and altitude, which is contained in the full data block. The tracking function operates separately on the two subsystems. It has an automatic track start and acquisition feature. It maintains track files on all declared tracks.

The MSAW function includes altitude tracking and general terrain and approach path warning logic.

The keyboard input processing function accepts data from the DEDS and TCDD keyboards and performs the desired function.

The display output function gathers data from the tracking function, keyboard input function, MSAW function, and the interfacility processing and prepares it for output to the displays. This function will output to the DEDS through an MDBM and to the TCDD via the CMC and RDBM.

The interfacility flight plan processing communicates with the ARTCC computer. This function accepts flight plan information and passes this data to the tracking and display output functions.

The continuous data recording function controls the recording of ATC data on the disc.

In the event of a hardware failure in the data processing elements, the system has first level backup, and second level backup programs to match the available hardware resources. Reduced levels are attained by reducing the data base and by eliminating some tasks. To simplify the assembling and building of operational systems, backup levels are created by eliminating entire tasks while retaining the full capability of the remaining tasks. This method of reduction provides a manageable number of task configurations.

The reduction from one level to the next shall be accomplished by the Recovery Module. Critical data previously recorded is used to establish a data base for the reduced version.

Data Base - The ARTS-IIIA data base includes all data used by any task. Data used by more than one task shall be defined as system data. Data used exclusively by any one task are defined as local data for that task. Task interface and communication are accomplished through the data base.

System Modifications - Several design deficiencies in the SRAP and CMA were discovered during system development that had to be resolved before operational cutover. These modifications have been made and both the CMA and SRAP are performing to specification.

SRAP Modifications - During SOST and pre-commissioning flight checks, several problems became evident in the performance of the RDAS part of the SRAP that required both hardware and software modifications to resolve. The modifications have been made and evaluated and the SRAP is now at a point that is considered state-of-the-art for non-Moving Target Detector (MTD) radar digitizers.

SRAP Quality Filter Modifications - During normal operation, the SRAP will use radar normal video for declaring target reports. However, radar Moving Target Indicator (MTI) video is used instead of normal video in those areas containing ground clutter. MTI video will contain clutter residue which will be declared as target reports which can cause the ARTS-IIIA to be overloaded. In order to regulate the number of radar target reports, a quality filter was designed to regulate by desensitizing within zones where persistent returns occur. Filtering is performed only on radar-only reports, i.e., those left over after attempted correlation with beacon reports. The quality filter is based on a partitioning of the surveillance area into 32 sectors, each containing 344 cells. The cells vary in size as indicated below:

Range 0 to 16 miles	-	128 ACPs by 1 nm
8 to 16 miles	-	64 ACPs by 1 nm
16 to 32 miles	-	32 ACPs by 1 nm
32 to 64 miles	-	16 ACPs by 1 nm

NOTE: ACPs = Azimuth Change Pulses

A numbering system uniquely defines the position of each cell within a sector.

A clutter cell scan file is maintained, containing one 16 bit word for each active clutter cell. Data stored consists of a cell number, quality threshold and a hit indicator. The file contains space for approximately 1500 active clutter cells.

Each radar-only report is subjected to a quality test if an active clutter cell exists containing the position of the report. If the quality of the radar report is greater than the quality threshold of the clutter cell, it is declared a true target. If a target is declared a true target, the hit indicator for that clutter cell is incremented. The hit indicator is then used to increment or decrement the quality threshold.

SRAP Amplitude Threshold Regulation Modification - In order to avoid ground clutter residue present in MTI video from generting active clutter cells in the quality filter, MTI radar reports are subjected to an amplitude threshold control prior to the quality filter but after the rank order quantizer. This threshold provides regulation of false clutter reports due to low level MTI breakthrough. The threshold level is based on a count of the number of radar-only reports each scan. This count is fed back to the RDAS from the CPS after Radar/Beacon correlation.

SRAP Weather Modifications - The Sensor Receiver and Processor (SRAP) provides a two-level weather map, light and heavy, with an area resolution of 32 range cells by 32 ACPs. The weather level, light or heavy, is measured independently within each weather resolution cell and is presented on the display by means of textured radial line segments (solid for heavy weather and dashed for light weather). Both light and heavy weather maps utilize radar normal video for measurement. The video characteristic measured is azimuth correlation and video amplitude. The light weather map is based solely on correlation, and the heavy map is based on both amplitude and correlation. Normal radar video from an Airport Surveillance Radar contains ground clutter out to approximately 20 miles depending on the radar antenna tilt. The SRAP cannot distinguish between radar returns from ground clutter and weather.

Therefore, the SRAP will declare heavy weather out to approximately 20 miles since ground clutter will pass the SRAPs amplitude and correlation tests. To correct this problem, a ground clutter (GC) region is defined within which MTI video is utilized for weather measurement. When a weather resolution cell lies within the GC region, the MTI isolated hit count is utilized for weather declaration. A single threshold is employed in this region and threshold crossings are interpreted as heavy weather. Consequently, the light weather map in this region will be identical to the heavy.

<u>CMA Modifications</u> - During final software development leading up to SOST when the entire DPS resources were being used, it became evident that a hardware problem somewhere in the IOP, CMA, Memory Module interface was causing numerous memory address parity errors. In a modern high speed DPS where the occurrence of a memory parity error is unusual, a frequency of one error every minute or so is clearly intolerable. After a time of treating the errors as a maintenance problem, it became obvious that an extensive investigation into the design of the IOP, CMA, MM interface was needed. This was done and covered every possible aspect of the designs and finally centered on the CMA. The problem was determined to be caused by excessive crosstalk between parallel lines in the CMA backplane. A contributing factor to the excessive noise was the existence of a ground-loop problem on several CMA address driver Printed Circuit Boards (PCBs) that caused noise spikes on switching at high current loads.

To solve the CMA backplane problem, a new backplane was designed and constructed using twisted pair interconnections for the address and data lines. In addition, the production CMAs were modified to use a backplane motherboard to avoid the production problems inevitable in the twisted pair approach. The address driver cards were also modified with wire jumpers to eliminate the ground loop problems. Production address driver cards were redesigned to eliminate these problems.

These fixes eliminated the address parity problems.

<u>System Testing</u> - The Tampa/Sarasota Radar Remoting system has undergone a complete series of acceptance tests designed to assure compliance of the new and modified hardware, test software and the operational program with the requirements of the system design data. The testing included hardware unit testing, subsystem testing, and operational testing.

<u>Unit Testing</u> - The purpose of unit testing is to demonstrate that each separate hardware device conforms to the specifications to which it was designed. This includes measuring and recording various system parameters, and verifying unit operation by using test software and standard diagnostics.

<u>Subsystem Testing</u> - The purpose of subsystem testing is to verify that the subsystems that comprise the total system are properly interfaced. This is accomplished by the use of computer programs specifically designed to check all the functions of the interfaces, such as data transmission, command code recognition, interrupt handling, etc. Interfaces tested this way include the IOP and the CMA/Memory Modules, the RDBM/TCDD, CMC, MDBM, SRAP and MSP.

<u>System Testing</u> - The purpose of system testing is to verify that the system is ready to be commissioned as an ATC facility, and that it performs all ATC functions specified in the system design data. The system operation is verified by performing a system baseline procedure. This is the standard ATC functional test has been developed over several years of ARTS operational experience. Modifications to the baseline procedure were made to reflect the changes and additions in the ARTS-IIIA Radar Remoting System. This test includes legal and illegal keyboard entries, ARTCC interface, Display functions, Tracking, Flight Plan processing, CDR Extractor and Editor, Remote Displays, Remote Radar Processing, Failure Modes, and System Capacity. After all ATC functions are

verified, the system is run for a period of 72 hours while being exercised in a simulated ATC environment using live traffic. This test must be completed before system cutover. Pass/fail criteria are established beforehand that defines how many, if any, failures are allowed in any unit or subsystem before the test must be restarted.

System Cutover - After the completion of system testing, all outstanding known hardware and software discrepancies were resolved in preparation for cutover.

Certification procedures prepared specifically for the Tampa/Sarasota Radar Remoting system by the Airways Facilities Service were completed. The system was then certified by the Airways Facilities Sector at Tampa as ready for operational use by air traffic controllers.

On May 26, 1979, cables were exchanged between the old ARTS-III and the new ARTS-IIIA Radar Remoting systems. The system was commissioned by Tampa Air Traffic operations and put into daily ATC service.

Cutover of the remote towers was scheduled to begin two weeks after the Tampa system cutover and proceed at a one site per week rate until all three remote sites and the Tampa Tower were in operation.

System Evaluation - After all remote sites were operational, an evaluation period of six months began. The evaluation is only for the remote all digital display of ATC data on the TCDD. This will include TCDD capability and controls, new digital display symbology, digital weather presentation, digital map presentations, radar only tracking and keyboard functions.

Data for the evaluaton is gathered by a questionnaire completed by all journeymen controllers after a two month familiarization period. A second questionaire is completed four months after the start of the evaluation to confirm the first evaluation and to determine what effect an additional two months of experience had on controller attitudes. An evaluation report will be prepared and delivered six months after the start of the evaluation so that it may be included in the Remote Radar Processing Technical Data Package.

Conclusion

This FAA project is another major step forward in the evolutionay growth to a full digital terminal operation. Expected benefits are: wider use of available radar information, fewer siting restrictions for terminal radars, improved ATC coordination between IFR rooms and remote towers and lower communication costs due to the substitution of digital circuits for the more expensive radar microwave links (RML) now used to transmit radar information.

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DABS DATA LINK APPLICATIONS DEVELOPMENT PROGRAM

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BIOGRAPHY

John J. Bisaga is Chief of the Data Systems Branch and is currently responsible for the definition and conduct of the Discrete Address Beacon System (DABS) Data Link Applications Development Program. He received his B.S. and M.S. in Electrical Engineering in 1955 and 1963, from Drexel University. Before joining the FAA in 1975, he occupied a wide variety of junior and senior engineering research and development positions in industry with responsibilities ranging from component and subsystem design through the design of complete communications and radar systems. Since coming to the FAA, Mr Bisaga has worked on the AEROSAT Program and has contributed to the establishment of several communications programs in the FAA. The Data Systems Branch is also responsible for the design of the enhancements to the National Airspace Data Interchange Network (NADIN).

ABSTRACT

The DABS Data Link Applications Development Program has as its principal objective the development, evaluation and demonstration of the benefits and methods of using the digital data link capability inherent in the signal structure of the DABS sensor to transfer air-ground aviation related messages of many types. The program will define the ground-side interfaces and information sources necessary, the means of formatting the information on the air-ground link and the required pilot or flight cre and controller interactions, if any.

Maximum flexibility will be permitted on the aircraft side so that the user can select from a wide variety of display output techniques which are appropriate to the data link services he desires and the price he can afford.

Many applications of data link have been identified which will be implemented as ATC and Flight Advisory services in an evolutionary manner over a period of years. Current emphasis in the program is the detailed definition and development of a near-term package of services that could be implemented in the same time-frame as the DABS sensors, i.e., the mid 1980's. A series of early experiments and demonstrations were conducted during December 1978, January and May 1979 on the most promising near-term services. Formal test and evaluation of these near-term service candidates will begin in late 1980 at NAFEC, using the DABS sensors which have been installed there.

BACKGROUND

The notion of using an automatic data link to connect the ground ATC automation system and other data sources and sinks to the aircraft has captured the imagination of ATC system planners for several decades. As a result of continued user interest, coupled with technology availability, the FAA has launched an R&D program specifically designed to bring data link services into being for a wide variety of users within the next 5 to 7 years. The introduction of these air-ground data link services is visualized to be evolutionary over a period of years, starting with an early mixture of a limited number of ATC automation, weather delivery and terminal information services provided to both general aviation and air carrier users of the airspace. These will be followed by enhanced and new services which will be defined in greater detail as the program progresses.

Data link services are currently being developed as a supplement to voice communications. At first, ATC services will be largely confirmation ones; i.e., a data linked equivalent to an already accomplished voice transaction. Eventually data link may replace some voice transactions, thereby lowering communication workloads. It is extremely doubtful that voice will ever be completely replaced by data link communications. There are many times when an interactive conversation is necessary between pilot and controller. Data link (requiring manual inputs of some type) is not the right way to do this.

The objective of the DABS Data Link Applications Development Program is to develop, evaluate, and demonstrate the benefits and methods of using the DABS digital data link capability to provide services in an evolutionary manner. The program will define the ground-side interfaces and information sources necessary, the means of formatting the information on the air-ground link and the required pilot or flight crew and controller interaction, if any. Maximum flexibility will be permitted on the aircraft side so that a user can select from a wide variety of display output techniques which are appropriate to the data link services he desires as well as the price he can afford.

The link design will specifically allow for the interface with a full range of avionics. This will give industry wide latitude to innovate and develop low cost avionics for the full spectrum of users. A National Standard will be necessary only to define the services available and how the information is contained in the link transmission.

The initial package of services is being developed to minimize controller and pilot manual interaction with the data link, and reasonable success has been achieved in the initial designs.

The DABS Data Link Applications Development Program is a recent addition to the RE&D Program. Preliminary work was begun in 1977 when an ad hoc committee was formed in the FAA for the purpose of examining the potential for enhanced safety, productivity, and capacity offered by DABS data link and defining the most promising near term applications. FAA offices which participated included Systems Research and Development Service (SRDS), Office of Systems Engineering Management (OSEM), Air Traffic Service (AAT), Flight Standards Service (AFS), National Aviation Facilities Experimental Center (NAFEC), and the Department's Transportation Systems Center (TSC). The committee developed a comprehensive list of data link services and ranked them according to priority and ease of implementation.

The work done by the committee (Reference 1) demonstrated that sufficient potential existed in the near-term applications to serve as the basis for a research and development program.

The applications identified were subjected to further analysis and review by SRDS, the FAA operating services, potential users of the services, and industry representatives. The near-term services identified for development, demonstration, test and evaluation are discussed in the next section.

The test and demonstration program, together with expanded avionics development, will more fully define the operational aspects of these data link services. This will take place over the next year and lead to formal test and evaluation activity at NAFEC beginning in late 1980. At the same time, the program will study additional enhancement candidates for longer range implementation.

PRODUCTS/EXPECTED RESULTS

Near-Term Data Link Services

Two fundamental criteria were used in selecting the development candidates for the near-term DABS data link test and demonstration program:

a. The services had to have the potential of contributing to the safety, capacity or productivity of the system from the perspective of the operators and users.

b. Each of the services had to be capable of implementation in the near-term (by the mid 1980's).

The implications of the former criteria are obvious: It requires concentration on those aspects of the system where the data link can provide some degree of operational improvement. Current operations require human delivery of ATC services, which is often an inefficient use of resources, can contribute to the occurance of system errors, and is sometimes detrimental to the performance of the primary responsibilities of the controller and pilot. The limitations of current equipment often preclude a data link from improving the service currently being provided.

The major implications of the latter criteria are:

a. Test and Evaluation activity must be completed in the early 1980's to permit implementation by the mid-1980s.

b. The services to be provided must be coordinated with other FAA programs which provide the basic data sources and information sinks.

c. Controller interaction with the data link must be minimal. Optimum controller terminal devices are under development (References 2 and 3), but are not scheduled to be available for test and evaluation in time to support the demonstration program for the near-term services. Longer range enhancements and new services will be developed to use these new terminal devices.

d. Data link usage of the ground ATC automation capability must be based on current field functions or those enhancements which are well along in development and within the capability of the current computers to provide. Future enhanced data link services will be designed to include the automation features currently being studied by FAA's advanced planners.

A final point should be made before discussing the services selected as near-term candidates. None of the services can be made available to the airspace users unless they are equipped with DABS transponders and minimum input/output devices. On the other hand, the users will not be motivated to so equip unless the services are available or are demonstrated to be imminent. Therefore, any program designed to provide high utilization of data link services must be implemented on the ground first, and the necessary standard issued. The innovation by industry necessary to develop the low cost avionics will follow.

The data link services which have been identified as candidates for near-term implementation are:

a. Automatic Traffic Advisory and Resolution Service (ATARS)- ATARS is an automatic traffic advisory and conflict resolution service provided by a totally automated ground computer system (Ref. 4). It is an outgrowth of the IPC concept which was described and recommended for development by the Air Traffic Control Advisory Committee (ATCAC) in 1969. Aircraft separation assurance is achieved by continuously providing pilots with traffic advisory information on the location of proximate and threatening aircraft and by issuing resolution advisories on an "as needed" basis. In this way the safety of civil air traffic is improved while maintaining freedom of flight for the VFR community to the maximum extent possible.

b. Takeoff Clearance Confirmation - Takeoff clearance is presently transmitted from the controller to the flight crew by voice link. A data linked takeoff clearance confirmation, provided in a manner that would allow the flight crew to confirm that clearance exists at a glance, would prevent any possibility of misunderstanding between the crew and the controller.

c. Minimum Safe Altitude Warning (MSAW) Advisory - In all 63 ARTS-III terminals, the approach controller is provided a warning if the approaching aircraft is in danger of descending below the minimum safe altitude programmed into the computer. The controller must then relay this warning to the flight crew. This warning could be sent directly to the crew via data link, thus potentially reducing the delay between detection and warning transmittal.

d. Altitude Assignment Confirmation - During en-route phases of flight, changes in altitude are directed to the flight crew by a controller using voice communication. Past occurences of misunderstanding of an altitude assignment or garbled transmission have led to altitude clearance violations and indicate that changes in the present system of altitude assignment must be investigated. Providing a confirmation of the altitude assignment information to the flight crews via data link overcomes the potential errors inherent in the voice system. Any misunderstanding highlighted by the confirmation would be resolved by voice communications.

e. Selected Weather - En route weather information is currently provided by voice communication to the flight crews and general aviation pilots. The Aviation Weather Systems Program (Reference 5) will have a very large weather data base available on line. The delivery of this information on request to the cockpit without controller or flight service specialist involvement not only makes the needed information available to the pilot, but reduces the human workload as well. Hardcopy for future reference can also be obtained easily, if the aircraft is suitably equipped.

Weather products currently included as candidates are:

- Surface Observations
- Weather Radar Summary
- Terminal Forecasts
- Alert Weather Watch
- Winds Aloft Forecasts
- Convective SIGMETS
- PIREPS

These products will be delivered on request to the cockpit for pilot-specified location (using a LOCID) and time. In the case of winds aloft forecasts the pilot also specifies altitude and the report provides the requested altitude forecast and also forecasts at 4000 feet below and 4000 feet above that altitude. Other products related to providing hazardous weather avisories in the cockpit are being investigated for the next phase of services.

f. Enhanced Terminal Information Services (ETIS) - At many airports, terminal departure and arrival information for the pilot is currently provided by the Airport Terminal Information Service (ATIS), a broadcast voice recording transmitted on a frequency separate from departure and arrival controller position frequencies. The program is developing an enhanced terminal service whereby this type of information will be provided to the cockpit via the DABS Data Link signal. This concept under development is called the Enhanced Terminal Information Service (ETIS). ETIS will enhance the current ATIS system which has some of the following limitations:

1. A controller or flight service specialist must record the information at prescribed intervals, such as one hour, or when weather or other conditions change significantly. This involves operational workload and means that the information is sometimes out of date, especially if the workload is heavy.

2. The line of sight characteristic of VHF transmission and lack of ground information netting limits the range from the airport over which a pilot can receive ATIS.

3. Because ATIS is a broadcast service, a pilot cannot selectively choose or continuously monitor one or more items of interest and ignore the rest. He must listen to the entire broadcast.

4. Hardcopy (a record) cannot be obtained easily. If the pilot desires a record, he must write it himself.

5. The tape recorders currently in use are aging and have been identified as a source of maintenance problems.

The ETIS concept (Reference 6) being developed will eliminate many of these shortcomings and provide several additional benefits to both the controller and pilot. The arrival ETIS concept (as it will be implemented at NAFEC for the early T&E) provides the terminal conditions to a pilot on request. This data can be largely derived fom automated sensors and requires only a minimal controller input. This full ETIS message will include in addition to runway(s) and approach(es) in use, pertinent weather information such as cloud height and coverage, visibility, runway visual range (RVR) if below minimum, runway winds (if the runways are equipped), temperature, dewpoint, altimeter settings, and any weather alerts available such as windshear. Thunderstorm alerts can also be included when adequate detection systems are available. The full ETIS message is flexible enough to add other information at a later time.

As the aircraft proceeds into the terminal area, makes its approach, and lands, additional pertinent data and changes in data are automatically dispatched to the aircraft at the appropriate points in the flight and depending upon the local conditions. Such data may include RVR, significant parameter changes such as altimeter setting, wind shear alert, etc. On a calm, VMC day, it is conceivable that the only ETIS message dispatched after the initial arrival message may be wind on final approach.

In addition to this full ETIS, the concept provides that the pilot will have the option of requesting ETIS information without updates for any suitably equipped airport at any point in his flight, as long as the aircraft is within coverage of a DABS sensor. The netting arrangements needed to provide this level of sevice as well as automatic dispatch of the arrival ETIS message described above will not be implemented at NAFEC this fall but will be considered in the enhancement phases of ETIS.

Program Milestones

The program to develop these candidates and further select from among them for early implementation is divided into three phases.

The first involved a period of early demonstration and experimentation in late CY-1978 and early 1979. This experimentation used a general aviation type aircraft outfitted with a set of experimental avionics (described later in this paper). The ground system was the DABS Experimental Facility (DABSEF) at Lincoln Laboratory. Appropriate hardware and software modifications were made to support experimentation with the candidate services. Sensors for some elements of the ETIS were located on Hanscom Field. Test flights used that airport. Limited functions of the Applications Processor (AP) (described in the next section) were implemented in the DABSEF computer. An interface with the flight services weather data base located at MITRE/METREK in McLean, Virginia, was established to retrieve the weather products to be provided. No ATC automation interfaces existed, but these functions were simulated in the DABSEF. The alphanumeric information on the link was coded using 6 bit truncated ASCII. This was an expediant measure for the time being to permit early experimentation. It is expected that ultimately special encoding of the information will be used to optimize link capacity. The main purpose is to experiment with the candidate services and obtain a first order assessment of their utility and methods of providing the services.

The second phase of development of the candidate services will occur in 1980 when further work will be done using the DABSEF. A new generation of avionics will be available which will have both alphanumeric and graphics capability (for future services experimentation). High efficiency link information formats will be developed for the candidate services and will be used with this work phase. A model of the Applications Processor will be available at this time to provide the necessary interfaces and processing functions. ATC functions will still be simulated in DABSEF software and hardware and Hanscom Field will still be the base of flight operations.

Current plans are to move the program activity to NAFEC for formal test and evaluation of the candidate services during 1980. The DABS equipment currently installed at NAFEC will be used for this activity. An Applications Processor will provide the necessary interfaces. Appropriate sensors will be installed at NAFEC or existing ones will be used if possible. Test ATC software for the en route and terminal automation interfaces will be available in the System Simulation Facility and the Terminal Automation Test Facility respectively. Aircraft used will include NAFEC test aircraft and hopefully some air carrier and general aviation aircraft. The ouput from this activity will be data to be included in a Technical Data Package which will support possible implementation of the finally selected services.

TECHNICAL APPROACH

Air Ground Link

The technical approach is to use the air-ground data message delivery and reception capability of the DABS sensor (Reference 7) to provide the fundamental air-ground data link. These messages can be transferred as an integral part of the transaction necessary to obtain surveillance data for aircraft tracking as shown in Figure 1. The aircraft, of course, must be equipped with a DABS transponder and appropriate input/output devices. Output devices could include electronic and/or mechnical devices of many kinds, depending on the type of aircraft and the services desired.

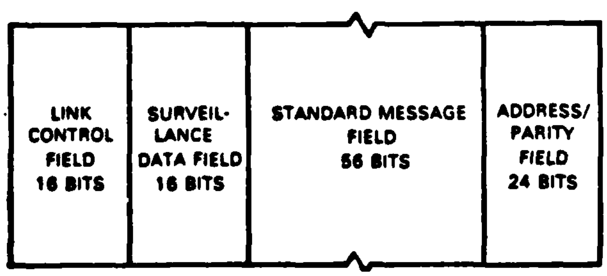

FIGURE 1
DABS NORMAL DATA BLOCK FORMAT

Ground Environment

The DABS sensor has been designed to provide all the necessary data link channel management to ensure accurate delivery of a properly formatted message to an aircraft within its responsibility. Formulating the message, routing of downlink information requests, retrieval of information on request and performing any processing functions dependent on a particular data link service are not the responsibilities of the DABS sensor. Much of the source information is available at the facility (the en route center, the TRACON/tower and the flight service station) and not the DABS site. There is, therefore, a requirement for data link processing capability at the facility. This is provided by the Applications Processor (AP).

Figure 2 shows the overall system concept being pursued in simplified form. The DABS site has a surveillance line to each ATC facility over which target tracking reports are sent. The AP will have a drop on this surveillance line. In addition, full duplex communication lines will exist between each DABS site and each ATC facility. One line will connect to each of the facility automation computers to provide the ATC message services (e.g., MSAW advisory and altitude assignment confirmation). Others will connect to an Applications Processor (AP) at each facility which will perform the necessary functions for all other services, including the ground-ground netting via NADIN (Reference 8). The AP will provide interfaces for all information sources. The information source for the weather services will be the Flight Services Data Processing System (FSDPS) (Reference 5). NADIN will be used to connect the AP with the FSDPS, when necessary.

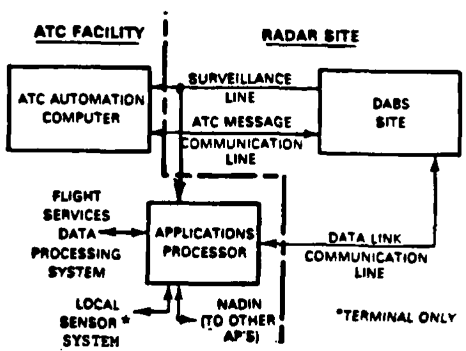

FIGURE 2
SIMPLIFIED DATA LINK SYSTEM CONCEPT
(INITIAL IMPLEMENTATION)

The AP will integrate all the inputs to and formulate the ETIS report and provide the retrieval and delivery capability. Any ground filtering provided will be done in the AP. The AP's at the various facilities will be netted using NADIN. This will provide remote services and ultimately will permit continuous data link coverage as the aircraft moves from sensor to sensor.

The DABS site contains the logic to handle the multiple inputs and resolve priorities. The ATARS and ATC messages will be given priority over others.

In the initial implementation for test and evaluation at NAFEC, the two communication lines previously mentioned will be used (one for ATC messages and one for all others). In the enhancement program, the two lines may be reduced to one (particularly for en route situations) with the AP providing the multiplexing function as well as any other functions necessary such as code conversion and priority resolution.

Avionics Development

A data link airborne terminal was developed during 1978 for use in the initial data link demonstrations and experimentation conducted in late 1978 and early 1979 at Lincoln Laboratory. Because of the limited time available for the procurement of the first generation airborne terminal, maximum utilization was made of off-the-shelf hardware. The first generation terminal used a color CRT for the split screen display of alphanumeric data plus an alphanumeric keyboard with multi-function keys (Figure 3). The top 4 lines x 21 characters of the CRT display the downlink message. The middle 4 lines x 32 characters display the uplink message received as a result of a downlinked request and the bottom 4 lines x 32 characters display an unrequested uplink message. A printer was provided that, when activated via the keyboard, printed the information as displayed on the CRT. The messages shown in Figure 3 are typical of those which might appear. See SRDS's 1978 progress report for more detail on this equipment (Reference 9).

A second generation data link airborne terminal is currently under development. This new unit will have capabilities which might be representative of high end general aviation or air carrier avionics of the mid-1980's. The new system is composed of 4 elements (Figure 4).

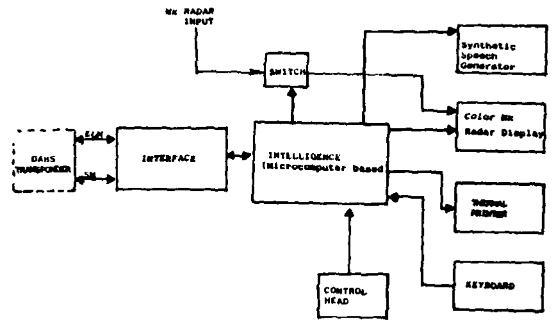

FIGURE 4
SECOND GENERATION
DABS DATA LINK AIRBORNE TERMINAL

1. Interface with DABS Transponder
2. Intelligence
3. Output devices
4. Input device

The airborne terminal will accept data from both the standard message (SM) and extended length message (ELM) interfaces of the DABS transponder. Current thinking is that most ATC messages can and will use DABS Comm A messages (Reference 7) which emerge on the SM interface of the developmental transponders available. Weather services require longer messages and will use the extended length message capability of DABS. These messages emerge on the ELM

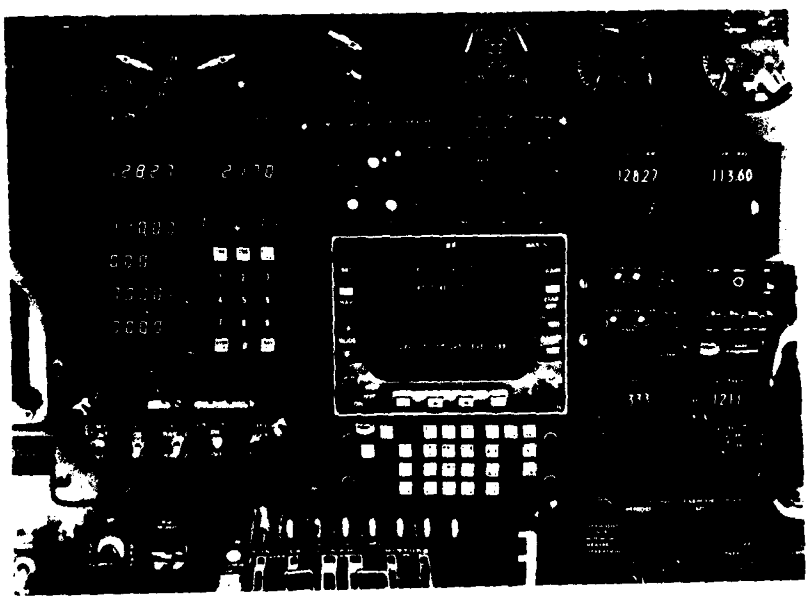

FIGURE 3

PHOTO OF FIRST GENERATION AVIONICS INPUT/OUTPUT DEVICES IN CESSNA 421 COCKPIT interface of the developmental transponders. The data messages will be bit oriented and will require a level of intelligence to recognize the type of message, assign priorities, interpret the meaning of the data, and format the message for display along with prestored information as required for that particular message type. Finally the message will be displayed on the CRT or hardcopy provided via the printer. The same color CRT display will be shared by data link, ATARS and conventional weather radar functions. The information displayed at any given time will depend on the existance of one or more data link or ATARS message(s) and their assigned priorities plus the mode of operation as selected by the pilot using the control head.

The CRT display is divided into two display areas (Figure 5). The upper 3 lines are reserved for the display of tactical messages. The tactical messages, listed in order of decending priority, include:

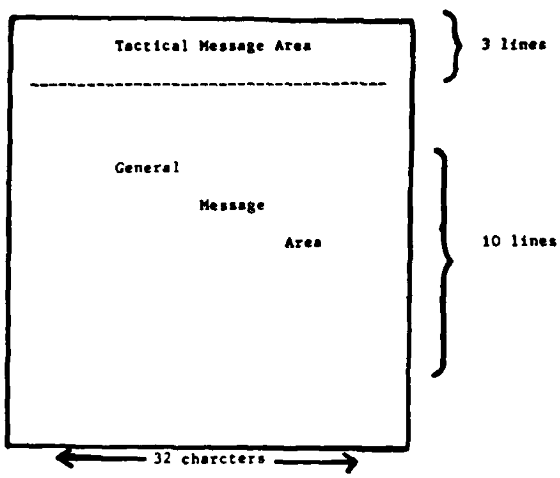

FIGURE 5
AIRBORNE TERMINAL DISPLAY

MESSAGE	PRIORITY
o ATC Critical Messages	1
o ETIS Alerts	2
o ATC General	3

The lower 10 lines of the display form the general display area. Messages to be displayed in this area include:

MESSAGE	PRIORITY
o ATARS Threat Advisory	1
o Keyboard Prompting	2
o ATARS Proximate Advisory	2
o Weather Messages	3
o ETIS Messages	3

When ATARS Threat Advisory (Priority 1) is being displayed, the general display area will be expanded to 12 lines if, and only if, the additional 2 lines are required for the display of the threat traffic. When this does occur, ATC critical messages or message pending information will be displayed on the single remaining line. Conversely, if no ATARS messages are current, the entire display is available for other messages.

New Messages will displace existing messages of lower priority on the display. Up to 6 messages can be stored in memory for later recall. New messages of lower priority will go directly into storage and a message pending indication will be displayed along with the existing higher priority message. The system employs time-outs to eliminate messages that no longer are current.

An alphanumeric keyboard (Figure 6) is provided for entering downlink messages (mostly requests for weather products). The keyboard will be used in conjunction with menus displayed on the CRT to formulate a downlink request. The menu will be used to select the data link service desired. The pilot will then enter via the keyboard the specific information required for that particular service (i.e., Location ID).

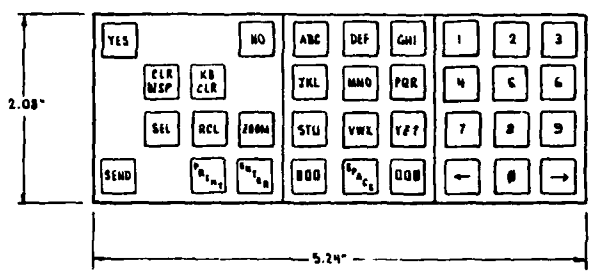

FIGURE 6
DATA - LINK KEYBOARD
(PRELIMINARY)

Our future avionics development plans include a low cost general aviation data link terminal. One concept under study is microprocessor based with plug-in firmware cartidges used for expanding the avionics capability to accommodate new data link services as they became available.

The airborne terminals described represent only a few implementations out of the many possible and are not considered optimum or standard. The FAA will implement both more complex and less complex airborne terminals for future tests. As previously stated, the development of standard avionics is not an objective of this program. We believe this is best left to the avionics industry and their wide range of customers, the air carrier and general aviation users of the airspace. The program will, however, define the services available, how they are to be used and how the information is sent over the link. The standard which will result will be the basis for the development by industry of the necessary spectrum of avionics.

SUMMARY

The development of ATC applications for the DABS data link which can be implemented by the mid 1980's is proceeding. Our test bed is nearly complete and test and evaluation of a first package of data link services will begin in 1980. The automation capabilities built into other FAA R&D programs are being used as the sources and destinations of many data link messages in this initial service package. New data link services are also being studied for inclusion as enhancements in the future.

Several versions of possible avionics equipment are being developed to support the development and testing of the candidate services. However, it is felt that operational avionics of many kinds will eventually be developed by industry once the services are fully defined and the appropriate standard is developed.

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DISCRETE ADDRESS BEACON SYSTEM

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BIOGRAPHY

P. Douglas Hodgins received his B.S. degree in Mechanical Engineering from the University of Maine in 1959. He served as Technical Advisor to the Navy AIMS and Landing System Project Office. He joined the FAA's Systems Research and Development Service in 1974 and served as a Branch Chief in the Microwave Landing System Division. Mr. Hodgkins has extensive major system development experience and was selected to head the DABS development program for the Communications Division.

BACKGROUND

In the previous progress report on the Discrete Address Beacon System published in 1978, the waveforms and a general description of the DABS computer subsystem were explained. The three DABS sensors under contract from Texas Instruments described in that report have now been delivered and installed; one is at the National Aviation Facilities Experimental Center (NAFEC) and the remaining two in the surrounding area (Elwood and Clemonton, New Jersey). The remainer of this report concerns itself with the acceptance tests conducted at the contractors facility and progress achieved in the field test and evaluation program being conducted at and by the National Aviation Facilities Experimental Center (NAFEC). For a complete description of the DABS concept refer to report FAA-RD-74-189.

PRODUCTS

Upon completion, in April 1980, of the testing currently on-going at NAFEC, a Technical Data Package (TDP) will be forwarded to the FAA's Airways Facility Service for procurement and implementation of DABS. A follow-on program is planned to provide an enhanced multisite netted version for linking overlapping sensors together in high aircraft density areas such as the Los Angeles Basin area in California. The TDP for the netted configuration is scheduled in April 1982.

Test and Evaluation - Factory Testing

Commencing in May of 1978, a series of system-level tests were conducted at the contractors facility to determine that the DABS sensor as developed by Texas Instruments met the specified engineering requirements as stated in reference 1.

The principal objectives of the factory tests with the first sensor were to determine: 1) target capacity, 2) range/angle accuracy, and 3) adequacy of the software for delivery and initial field testing. In May 1978, the hardware for all three sensors had been assembled, however, the software was integrated and tested in steps commencing with surveillance processing.

With regard to target capacity, special test equipment was developed called the Aircraft Reply and Interference Environment Simulator (ARIES) described in reference 2. Using an aircraft density model tape as input, the ARIES can generate up to 400 simulated transponder replies in any mixture of ATCRBS and DABS. In addition, the ARIES can generate a preselected percentage of the transponder equipped targets as primary radar targets to allow testing of the entire DABS surveillance function and system throughput.

The DABS sensor specification for target capacity is as follows:

> A peak of 50 aircraft uniformly distributed in an 11.25 degree sector for up to 8 consecutive sectors or 400 aircraft in a 90 degree quadrant.

The sector loading is based upon an aircraft density model forecast of the Los Angeles Basin (reference 3). This model was used to determine the peak sector load and the total capacity of the system. The sector peaks varied in azimuth for each of the interrogators in the LA Basin and therefore, the specification for the sensor to process 400 targets in 90 degrees was a convient way to insure the system would handle any combination of sector peak occurrences.

An ARIES test scenario was generated containing 400 targets in 90 degrees approximately equally divided between ATCRBS and DABS targets. This scenario was used for the factory tests to determine the processing capability of the sensor. The results of those tests demonstrated that the sensor was able to process all the targets and deliver target reports to the output port of the sensor within the specified time of 3/32 of a scan (375 milliseconds for a 4 second scan).

The accuracy tests performed at the factory were limited due to lack of a precision tracking system.* The tests, however, were adequate to demonstrate the basic accuracy of the sensor. The monopulse lookup table was generated for the particular antenna and the range azimuth errors determined with respect to a fixed transponder at a known location. The fixed transponder is an integral part of the system performance monitoring capability built into the sensor. This device is known as the Calibration Performance Monitor Equipment (CPME) and is described in reference 4. The accuracy requirement specified in the ER is 0.1 degree RMS for azimuth and 50 feet RMS for range over a range of received powers and frequencies. The measured accuracy at the factory was found to be .06 degrees and 15 feet for azimuth and range, respectively.

Other surveillance characteristics such as target declaration, target to track correlation, fruit rejection, and dissemination time were also analyzed.

The overall status of the software for the surveillance processing was judged by the test team to be adequate for supporting initial field testing and the first sensor was shipped to NAFEC on June 1, 1978.

The second sensor was ready for factory tests in December 1978. Formal test procedures were prepared and approved by the test team for testing data link and CIDIN communications, the Automatic Traffic Advisory and Resolution Service (ATARS), performance monitoring and

* Accuracy using a precision tracking system was later determined at NAFEC during field tests described later in this report.

failure/recovery in addition to surveillance. The Communications Test Unit (CTU) was used to simulate ATC facilities by recording surveillance and communications messages from DABS and providing Comm-A (data link) messages to DABS. ARIES was programmed to respond to the Comm-A messages and also to provide pilot initiated Comm-B messages. Following the evaluation of performance data by the test team, the sensor was shipped to Elwood, N.J. on December 15, 1978.

The third and final sensor acceptance tests were conducted in April 1979. These tests included software for multisite operations, radar/beacon correlation, and the back-to-back antenna system required for ATARS in the en route environment. Also tested was the Systems Test Console (STC) used to interact with and sample data from all three sensors. This device has become an invaluable tool for testing and may be incorporated in production for multisensor operation.

Again, the performance test performed on the first two sensors were repeated on the third with improved results as corrections had been incorporated for deficiencies found in the earlier tests. One of the most impressive tests performed on each sensor was system recovery following a computer ensemble failure. A computer ensemble, containing four mini-computers, was deliberately powered-off while tracking approximately 400 aircraft and the the sensor would completely recover all aircraft tracks within 10 seconds.

Again, overall performance was deemed satisfactory by the test team and the sensor was shipped to Clementon in late April 1979. All factory testing was complete with the third sensor, including an interface device for the en route 9020 computer at NAFEC. This device called a Front End Processor takes the communication outputs from the DABS sensor, which are in ICAO recognized CIDIN Format, and reformats the data for the 9020 computer.

Field Testing

Initial tests with the first sensor installed at NAFEC were essentially a repeat of the factory tests to insure system integrity after shipping. At the conclusion of the shakedown period and just prior to commencement of the formal test program, the new production five (5) foot open array beacon antenna became available and was installed for the tests. The "baseline" test program described in reference 5 was a more comprehensive set of test scenarios than those used during the factory tests. The "baseline" scenarios exercised the sensor to its limits in all important areas. Also, the system accuracy was determined using the 5 ft. open array monopulse antenna and the results indicate that the performance is well within system specification.

The baseline tests have been completed on the NAFEC sensor and a draft report is in preparation. The NAFEC sensor will then be tested with the new software developed for the terminal ATC system. The software has been developed under contract with UNIVAC and takes advantage of the improved accuracy and system performance available from DABS. The ATC system tests are expected to be completed in April 1980.

The second sensor, at the long range primary radar (ARSR-2) test site at Elwood, New Jersey, was installed with the unique back-to-back monopulse antenna system required for ATARS mentioned earlier. The antennas are versions of the terminal 5 ft. open array but modified to fit on the ARSR-2 primary radar - one is chin mounted on the feed horn support structure and the other attached to the back of the reflector screen. In addition to these two antennas, which are essentially copies of the terminal production antennas with regard to performance, a third lightweight version of the 5 ft. array is being developed with performance characteristics more suitable for long range use in the en route environment. This antenna is scheduled for delivery in January 1980. It is this latter lightweight antenna that is expected to be procured in production to meet the back-to-back antenna requirement. However, since there are no appreciable differences in performance between the two versions (light and heavy) that would effect ATARS, the testing will proceed at Elwood using the heavy antennas already installed. Results of these tests with the back-to-back antennas are expected to be available in the final baseline test report due in early 1980.

The Clementon, N.J. site was selected for the terminal ATARS testing because it presented an unobstructed view of the Philadelphia Terminal Area, being only 13 miles from the airport. The Clementon sensor is undergoing initial checkout at the time this report is being written and there are no results to present at this time. This sensor will be the primary development sensor for ATARS. It will also be used to integrate the interface modifications currently being developed by Texas Instruments to interface with various types of primary radars including the new Moving Target Detector (MTD). Interfaces are also being developed for military equipment that will be installed later at the Elwood site. In addition to the baseline testing and interface modifications testing mentioned above, NAFEC will be evaluating network management software which will support a configuration for netted and unnetted DABS operation.

<u>DABS Electromagnetic Compatibility Tests</u>

DABS electromagnetic compatibility tests on both the uplink (1030 MHz) and the downlink (1090 MHz) channels are being conducted to quantitatively determine the electromagnetic compatibility of DABS with the current operational Air Traffic Control Radar Beacon System (ATCRBS). On the uplink channel, the potential interference mechanism is the intentional suppression of ATCRBS transponders by DABS roll-call interrogations. Since the suppression pulses are only transmitted in the very narrow mainbeam of the DABS directional antenna, the volume of airspace affected is much smaller than the volume of airspace that is affected from an ATCRBS interrogator transmitting suppression pulses on an omni-directional antenna as is currently done in the present operational system. Hence, the average number of ATCRBS suppressions will actually decrease when DABS is implemented. The downlink tests are designed to determine the susceptability of ATCRBS ground processors to DABS asynchronous replies. Downlink tests have been conducted on some and will be conducted on all the different types of ATCRBS processors in the FAA inventory. Downlink tests to date indicate that there is no appreciable impact on ATCRBS processor performance for ATCRBS target detection and code validation in the presence of DABS asynchronous replies. For more details of the uplink and downlink tests conducted (see reference 6).

Summary

During the past year, significant progress has been made in the DABS program. Three engineering model DABS sensors have been factory accepted and installed in the vicinity of the FAA's National Aviation Facilities Ecperimental Center, Atlantic City, New Jersey, for test and evaluation. The test and evaluation program outlined in reference 7 is fully underway. The tests conducted to date have demonstrated that the engineering requirements are being satisfied, including the DABS interface compatibility with terminal and en route air traffic control facilities. The electromagnetic compatibility program tests thus far have demonstrated the compatibility of DABS signals with current operational FAA equipments. Reference 8 provides the details of some of the testing being performed at NAFEC and test result reports are expected to be published in early 1980.

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MOVING TARGET DETECTOR

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BIOGRAPHY

Donald H. Turnbull is the MTD Project Manager in the Communications and Surveillance Division of the Systems Research and Development Service. He received his B.S. in electrical engineering in 1968 from Duke University. He has taken graduate courses in administration at Southern Methodist University, George Washington University and George Mason University. Prior to joining the FAA in 1970 he worked for 2 years for LTV Aerospace Corporation, Special Support Equipment Division in Dallas.

ABSTRACT

This paper describes the development of the Moving Target Detector (MTD), an improved radar clutter processor. The MTD development program was established by the FAA to overcome the limitations experienced by existing Air Traffic Control radars in detecting small aircraft in the presence of clutter. The types of clutter experienced by these radars are ground clutter, precipitation clutter, angel clutter (primarily birds), ground traffic, and interference. The MTD utilizes Doppler filtering techniques to overcome these clutter problems.

A breadboard MTD-I was designed and fabricated by Lincoln Laboratory under the direction of the FAA. This system was interfaced with an ARTS-III system and evaluated at the National Aviation Facilities Experimental Center. The results of the evaluation were favorable and a decision was made to develop two MTD-II field evaluation model systems which were used for operational field tests at a selected terminal radar and an en route radar site.

BACKGROUND

Introduction

The MTD is an advanced radar signal processor developed by Lincoln Laboratory under the sponsorship and direction of the Systems Research and Development Service of the Federal Aviation Administration. The objective of the effort was to develop a processor that would overcome the problems that existing Air Traffic Control (ATC) radars experience in clutter environments; namely, poor detection of small aircraft and excessive false alarms. These problem areas are discussed in detail below. The MTD development effort has gone through three major phases. These are: 1) analysis of ATC radar problems and formulation of techniques for solving these problems; 2) design, fabrication and test of a breadboard MTD-I at the National Aviation Facilities Experimental Center (NAFEC) to prove the MTD concept; and 3) design, fabrication, and test of field evaluation model MTD-II's for both en route and terminal radars. At the present time, the terminal MTD-II evaluation is completed and the en route MTD evaluation is being conducted.

Problems With Existing Radars

As stated above, the FAA's existing ATC radars encounter difficulties in detecting small aircraft and experience excessive false alarms in clutter environments. The various types of clutter and their affect on the radars are discussed below.

Ground Clutter. At a typical FAA ATC radar site, ground clutter will extend out about 20 miles, although it can extend out considerably further in range in hilly or mountainous terrain. This clutter varies considerably from point to point because of the discontinuous nature of the reflectors (mountains, buildings, power lines, water towers, etc.) and the shielding effects of these reflectors. While ground clutter may look continuous on a display, in reality there are many "holes" in the clutter because of shielding.

Three basic techniques are presently used by FAA radars to reduce the effects of ground clutter. These techniques are: Moving Target Indicator (MTI), antenna tilt, and shielding. The MTI system utilized by the Airport Surveillance Radars (ASR's) employs a three pulse canceller with IF limiting. The purpose of the limiting is to perform a constant false alarm rate (CFAR) function so that the clutter residue is reduced to the average noise level and therefore is not displayed on the controller's scope. The disadvantage of limiting is that the clutter spectrum is spread out and the potential subclutter visibility (SCV) is reduced. Calculations made for an ASR-7 indicate that an improvement factor of 46 dB is required to detect a 1 m^2 target (typical small aircraft) at 15 nautical mile range, using typical clutter levels from mountainous terrain that are exceed only 5 percent of the time. Since the ASR radars have an improvement factor of approximately 25 dB, it can be seen that there are many times when it is not possible to detect small aircraft flying over ground clutter. The wide notch around zero velocity and the first blind speed due to MTI also creates detection problems. The blind speed problem can be eliminated through the use of staggered pulse repetition frequency (PRF), however, the notch around zero velocity means that aircraft will not be detected for a considerable number of scans when they are flying tangential to the radar. In an effort to reduce the area subjected to the tangential blind speed problem, the most modern FAA radars (e.g., ASR-8 and ARSR-3) utilize range-azimuth gating which essentially maps out the areas in which ground clutter is present and gates on the MTI only in those regions, thereby permitting normal (non-MTI) radar coverage in the areas in which no ground clutter is present.

Greater signal-to-clutter ratios can be obtained by tilting the antenna up, however, this sacrifices the low altitude coverage at longer ranges. The most modern FAA terminal (ASR-8) and en route (ARSR-3) radar systems utilize this technique to reduce close-in ground clutter by having dual beam antennas. At short ranges the upper beam is used to reduce ground clutter while the lower beam is used at longer ranges to maintain low angle coverage.

The third way existing FAA radars reduce the effects of ground clutter is through shielding. The selection of a radar site and determination of antenna height involves a trade-off between two conflicting requirements. Maximization of low altitude long range coverage would dictate a site with few close-in obstructions and a high antenna height. Minimization of ground clutter dictates a low antenna height and the presence of close-in obstructions to shield out sources of ground clutter. In siting a radar, the FAA must select the best compromise between these conflicting requirements.

Second-time-around ground clutter occurs during conditions of anomalous propagation when the radar waves are bent back to earth and are reflected from points beyond the normal range of the radar. In this situation, ground clutter returns from the next-to-last pulse are mixed in with radar returns from the last pulse. In FAA radars utilizing a magnetron transmitter (e.g., ASR-4, 5, 6, 7, and ARSR-1, 2) a fixed phase relationship is not maintained between pulses and therefore there is no way to filter out second-time-around ground clutter. In radars with coherent transmitters (klystron) the second-time-around clutter will be cancelled out by the MTI if a constant PRF is used. However, with staggered PRF the range of the second-time-around clutter will vary from pulse to pulse and therefore the clutter cannot be cancelled.

Precipitation Clutter. Returns from precipitation inhibit the detection of aircraft by saturating the controller's display and masking aircraft returns. This problem occurs on both terminal and en route radar systems; however, it is more severe on the terminal systems because precipitation backscatter on S-band systems (terminal radar frequency) is approximately 15 dB higher than that on L-band systems (en route radar frequency). The spectral spread of the precipitation depends upon the prevailing wind and the wind gradients within the precipitation area. The MTI circuitry will eliminate only the zero radial velocity components of the precipitation in the MTI regions.

FAA radars utilize circular polarization and Log-FTC-antilog circuitry to reduce the effects of precipitation clutter. Circular polarization improves signal to clutter ratio by reducing the precipitation backscatter about 16 dB while reducing aircraft returns by only about 2-6 dB. Log-FTC-antilog circuitry provides a CFAR function by automatically lowering the radar receiver gain at each range by approximately the amplitude of the precipitation return. This prevents precipitation clutter from saturating the radar display and permits detection of aircraft targets whose return is stronger than that from precipitation.

Although it is desirable to remove the precipitation from the controller's display to allow better aircraft detection, there is a conflicting requirement to present weather information to the controllers that will permit the separation of aircraft from potentially hazardous storms. Existing FAA radars can present only precipitation reflectivity and even that presentation is not properly calibrated for STC attenuation, MTI velocity response, antenna beam shape, and the use of circular polarization. Further, reflectivity has only an indirect relationship to areas of turbulence, in that severe turbulence may exist in areas of a thunderstorm other than the high precipitation reflectivity cores.

Angel Clutter. Angel clutter is a term used to describe radar returns which cannot be attributed to ground clutter, precipitation clutter, or aircraft. Experiments have been made which indicate that most angel clutter is caused by bird flocks.[2] Angel clutter problems are most severe during the spring and fall bird migration seasons. Returns from single birds at S-band range in size between 10^{-4} and 10^{-2} m^2 and although the mean return from a flock of birds is about 10^{-2} m^2 peak returns of bird flocks can be as high as 10 m^2. Since the return from a small aircraft is often about 1 m^2, it can be seen that discrimination between small aircraft and angels can be very difficult.[1&3] The problem is not limited to the FAA S-band (terminal) radars but also applies to FAA L-band (en route) systems since the radar return from large birds is resonant near L-band.

Ground Traffic. Many FAA radar systems are sited such that they receive radar returns from ground traffic on highways and bridges. Since this traffic consists of moving vehicles, these returns are not rejected by the MTI circuitry and are displayed on the controller's scope. At the present time, the only solution to this problem is to tilt the antenna upward or to blank out the areas which contain ground traffic.

Interference. Some FAA radar systems have problems with interference from other radiating sources on or near the same frequency. As the number of radars increase, it is expected that this problem will increase especially in high radar density areas such as the Los Angeles basin. The present means for reducing this problem is to employ the video integrator circuitry in the radars.

PRODUCTS/EXPECTED RESULTS

A breadboard Moving Target Detector (MTD-I) was designed and fabricated at Lincoln Laboratory and delivered to NAFEC. The MTD-I was interfaced with an Automated Radar Terminal System (ARTS-III) and given an extensive evaluation including a direct comparison with the most advanced radar video digitizer (RVD-4) developed by the FAA to that time. The MTD-I greatly improved small aircraft detection capability in all types of clutter environments. The ground clutter environment at NAFEC is shown in figure 1 with 5 mile range rings. The heaviest ground clutter is located about 7.5 miles southeast of the radar site and has peaks of 45 dB above noise level. A controlled aircraft was flown tangentially over this area and was detected continuously (figure 2).[4]

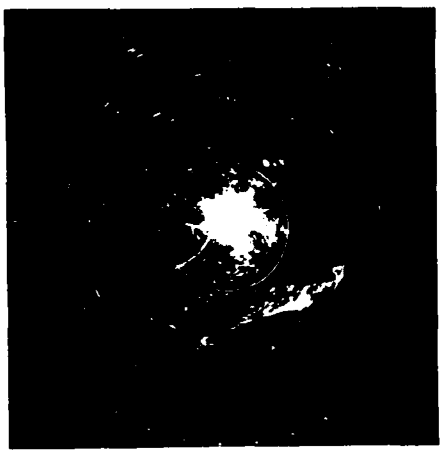

FIGURE 1. NAFEC GROUND CLUTTER.

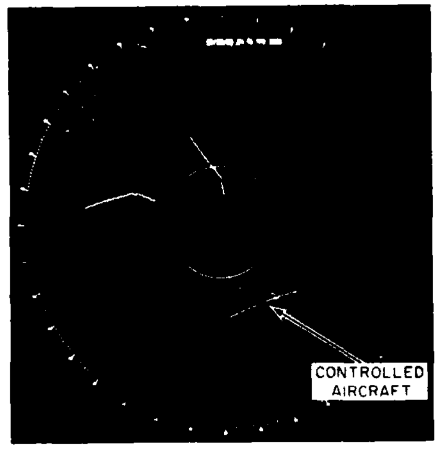

FIGURE 2. MTD PERFORMANCE OVER GROUND CLUTTER.

Figure 3 shows the normal video presentation of rain during an MTD-I test in which the amplitude of the rain varied between 0 dB and 40 dB. A test flight was made with a small aircraft in that rain and that aircraft was continuously detected (figure 4). Tests were also made of interference and angel clutter rejection capability. Ground traffic rejection was not incorporated in the MTD-I. The results of the test and evaluation of the MTD-I at NAFEC are described in a report published in October 1977.[5]

FIGURE 3. PRECIPITATION CLUTTER.

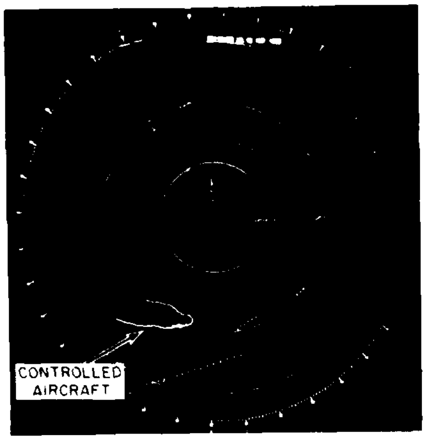

FIGURE 4. MTD PERFORMANCE IN PRECIPITATION CLUTTER.

Based on the results of the MTD-I evaluation the FAA made a decision to develop and fabricate two advanced MTD-II systems for operational field evaluation at a terminal and an en route FAA radar site. The terminal site selected was Burlington, Vermont. Burlington is a non-automated ASR-7 site located in mountainous terrain. It is also expected that there will be considerable precipitation and angel clutter at Burlington. The en route site selected is Bedford, Virginia. Bedford has an FPS-67 radar system which is remoted to the Leesburg, Virginia, Air Route Traffic Control Center. This radar is located on the top of a mountain. The Air Force partially funded the en route MTD-II program and is participating fully in the program.

The terminal MTD-II evaluation at Burlington, VT, has been completed. This evaluation consisted of both a technical phase and an operational phase using FAA air traffic personnel. A terminal MTD technical data package has been prepared and MTD techniques are being specified for the new ASR-9 system. An MTD retrofit program for the existing ASR-7/8 systems is planned.

The en route MTD-II evaluation at Bedford, VA, is scheduled to be completed by the Spring of 1980. It is anticipated that MTD techniques will be included in the new ARSR-4 system and retrofitted to the ARSR-3 system.

TECHNICAL APPROACH

MTD General Description

To accomplish the required clutter rejection the MTD utilizes velocity filtering and adaptive thresholding. The entire radar coverage area is divided into range-azimuth cells (1/16 mile by 3/4 degree cells for terminal, 1/8 mile by 3/4 degree cells for en route). Each azimuth cell is called a coherent processing interval (CPI) and contains eight pulses generated at a constant PRF. From these eight pulses a series of eight generalized digital Doppler filters are generated with each filter having a given velocity response (for example between 35 and 50 knots) so that the total response from all eight filters spans the spectrum between zero velocity and the first blind speed. The same filters repeat themselves for higher velocities. Each range-azimuth-Doppler cell is individually thresholded for clutter rejction.

Ground Clutter Thresholding. Nearly all of the ground clutter falls into the zero velocity filter with only a little spilling over into the adjacent low radial velocity filters. Because of the discontinuous nature of ground clutter, a fine grained dynamic ground clutter map is maintained to determine the level of clutter in each range-azimuth cell. The clutter map is built up and maintained in a recursive manner by adding 1/8 of the output of the zero velocity filter on each scan to 7/8 of the value stored in the map. In this way, the clutter map can adjust itself to changes in the clutter occurring in the zero velocity filter due to weather moving in or propagation changes. The value stored in the map is used to set the threshold in the zero velocity filter and to a much lesser extent the thresholds in the adjacent low radial velocity filters.

Aircraft which have velocities other than zero do not compete with the ground clutter in the zero filter and are therefore detected. Those aircraft with zero velocity would not have been in a range-azimuth cell long enough to build up the clutter map and therefore would be detected if they are stronger than the threshold in that particular cell. This is usually the case because aircraft with zero radial velocity are broadside to the radar which is the aircraft aspect giving the largest radar return.

Blind speed problems are eliminated through the use of batch staggering. Although the PRF is constant within a CPI, it is varied in alternate CPIs. In this way, if a target is in a blind speed during one CPI it will not be in that blind speed during the next CPI. Keeping a constant PRF during the eight pulses within a CPI permits the cancellation of second-time-around ground clutter if the MTD is interfaced with a radar having a coherent transmitter.

Weather Clutter Mean Level Thresholding. The Spectral return from precipitation varies in width as well as in average velocity. These returns can therefore fall into any Doppler filter and be spread over several filters. Unlike ground clutter, precipitation clutter does not vary greatly from cell to cell. For this reason, the threshold for each range-azimuth cell is obtained by mean level thresholding for the non-zero filters. In this scheme the amplitude of the precipitation (or noise) is averaged over one mile in range centered on the cell of interest and this average is used to set the mean level threshold. Any aircraft sufficiently stronger than the precipitation clutter will be detected.

For aircraft whose radial velocity is greater than the first blind speed there is a greater probability of being detected. The reason for this is that with the PRF varying from CPI to CPI the return from the higher velocity target will fall into different Doppler filters on alternate CPIs. This means that if this target is competing with rain during one CPI, it will probably fall into a rain free Doppler filter during the next CPI and therefore be detected.

Post Processing. Whenever a threshold is exceded in any range-azimuth-Doppler cell a primitive target is generated. A typical aircraft return may extend over two range cells, two or more CPIs, and several Doppler filters. The purpose of the post processing function is to process the primitive target reports into accurate aircraft position reports and to reject false alarms including those caused by angel clutter and ground traffic. The primitive targets seeming to come from one aircraft are grouped together into a cluster (correlated) and then an interpolation function is performed on the cluster to find the best estimate of azimuth, range, and amplitude of the target.

A second level thresholding is performed to reduce angel clutter. The radar coverage is divided into sectors. If an excessive number of returns occur in a sector in any filter, a threshold is set to eliminate the weaker returns. In this way angel returns which tend to be lower velocity weaker returns are eliminated.

False alarms are rejected by a scan-to-scan correlator. Each return is compared against returns from previous scans to see if it corresponds to an existing aircraft track. Only tracks that have lasted for three scans are sent to the display for use by air traffic controllers.

Ground traffic is difficult to distinguish from aircraft since it tends to have the same characteristics; i.e., it is moving, it can have large radar cross sections, and it can fall into any Doppler filter. Since the exact location of roads is known, radar returns from these areas can be displayed with a different format and these returns are not used to update or initiate tracks in the scan to scan correlator.

Interference Rejection. Non-synchronous interference will appear on only one pulse of the eight pulses making up a CPI. Each CPI is examined to see if one of the eight pulses greatly exceeds the average pulse amplitude. If this is the case, the entire CPI is thrown out during that scan. In this way non-synchronous interference is completely eliminated.

MTD Design. The basic block diagram of the field evaluation model MTD-II is shown in figure 5. The various functions are interfaced into a system through an IEEE standard data bus. This interface is controlled by the bus controller. The radar controller accepts antenna position information and the master IF oscillator signal and outputs all the necessary triggers and pulses needed by the radar.

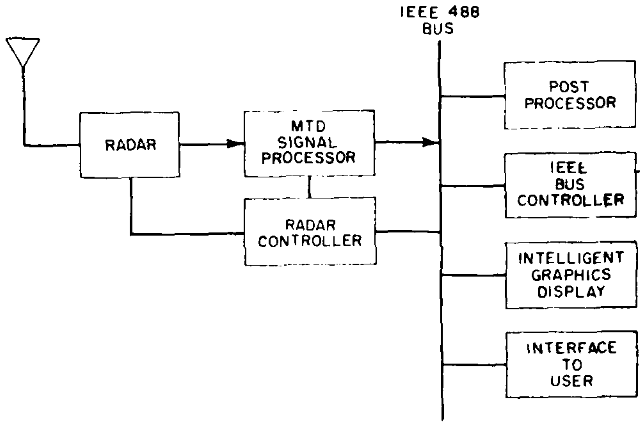

FIGURE 5. MTD-II BLOCK DIAGRAM.

The MTD-II accepts radar signals from the preamplifier which are then fed into a wide dynamic range receiver. Quadrature video detectors provide I and Q video to 10-bit A/D converters. The output of the A/D converters is fed into the parallel microprogrammed processor (PMP) which is the heart of the MTD. All of the Doppler filters and the ground clutter map are generated in the PMP. The PMP is a very fast processor which can be programmed using special PMP assembly language to perform many different functions. Any required change to the MTD algorithms can be implemented through a programming change.

The parallel structure of the PMP is shown in figure 6.[6] Each processing module (PM) is identical and contains input memory, auxilliary memory, and a processing element (PE) which performs the same function at the same time in all PMs. For example, in the terminal MTD-II PM #1 handles the data from 0 to 10 miles; PM #2 handles the data from 10 to 20 miles and so on. A spare PM is provided so that it can be automatically switched in to replace a failed PM. Automatic diagnostic routines will be incorporated in the PMP to detect faults and switch in the spare PM. If more than one PM fails, the MTD-II will degrade gracefully by readdressing the PMs so that only the furthest range data is lost.

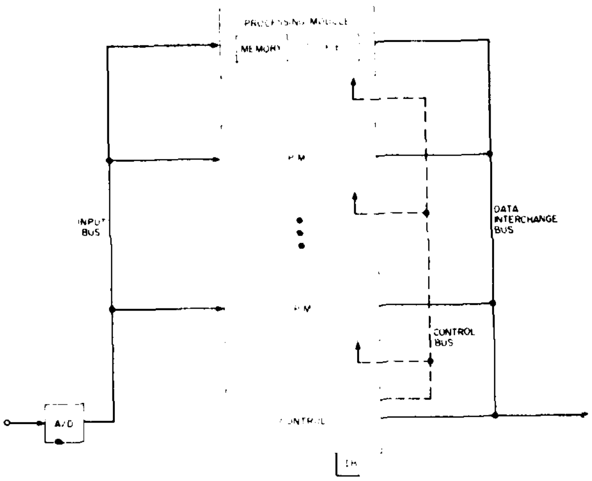

FIGURE 6. PMP BLOCK DIAGRAM.

Display Processor. Due to the correlation and interpolation function and the scan-to-scan correlation function, the MTD data is not available for display until approximately one second after real time. This means that the MTD radar reports are no longer lined up in time with the beacon reports and the video map information. In addition, the MTD radar outputs are digital position reports and are not suitable for presentation on an analog display. The purpose of the display processor is to reconstitute the MTD digital output into an analog rho-theta target "slash", delay the beacon and map information, and realign the sweep so that all the information is displayed with proper alignment to north and to each other. The display processor also takes the two-level weather outputs of the MTD and displays them as two levels of shading.

SUMMARY

Existing FAA radar systems experience difficulty in detecting small aircraft in the presence of ground clutter, precipitation clutter, angel clutter, ground traffic, and interference. In order to overcome these difficulties, an advanced radar signal processor called the MTD was developed. The initial breadboard version of the MTD was successfully tested at NAFEC. Two second version MTDs were developed for operational field evaluation at a terminal radar site (Burlington, Vermont) and an en route radar site (Bedford, Virginia). It is anticipated that MTD techniques will be included in all new FAA surveillance radar systems and will be retrofitted to those radar systems not scheduled for replacement.

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AUTOMATIC TRAFFIC ADVISORY AND RESOLUTION SERVICE

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BIOGRAPHY

Dr. Scardina is Chief of the ATARS Section, Separation Systems Branch, Communications and Surveillance Division. He received his B.S.E.E. in 1964 from Virginia Polytechnic Institute, and his M.S. and Ph.D. from the Georgia Institute of Technology in 1966 and 1968, respectively. Prior to joining the Federal Aviation Administration in February 1975, he was a group leader in the Air Transportation Division of the MITRE Corporation in McLean, Virginia. He has also been employed by the Safeguard Communications Agency, the MITRE Corporation in Bedford, Massachusetts, Georgia Institute of Technology, and Probescope, Inc.

Introduction

The Automatic Traffic Advisory and Resolution Service (ATARS) is a pilot oriented ground-based collision avoidance system based upon the earlier concept of Intermittent Positive Control (IPC). It utilizes surveillance data from the Discrete Address Beacon System (DABS), computes traffic and resolution advisories using a totally automated ground computer system located at the DABS sensor site and delivers these advisories to ATARS-equipped aircraft via the DABS data link.

The principal objective of the ATARS program is to improve the safety of civil aviation by reducing the probability of midair collisions and near-miss encounters that can result from:

(a) Aircraft deviations from assigned altitudes and/or routes due to pilot errors or equipment malfunctions.

(b) Air traffic control system errors.

(c) Air Traffic Control system hardware or software failures.

(d) The inability of pilots using see-and-avoid techniques to maintain safe separation from controlled and uncontrolled aircraft.

ATARS is being developed to provide pilots of ATARS equipped aircraft with a comprehensive traffic advisory service and an effective resolution service. For uncontrolled aircraft, the traffic advisory service will enhance the pilots see-and-avoid capability while the resolution service will provide collision avoidance services not previously afforded by the air traffic control system. In the case of controlled aircraft, ATARS will serve as a separation assurance backup to the existing air traffic control system.

ATARS System Description

ATARS is an automatic traffic advisory and conflict resolution service provided by a totally automated ground computer system. It is an outgrowth of the Intermittent Positive Control concept which was described and recommended for development by the Air Traffic Control Advisory Committee in 1969 (References 1 and 2). Aircraft separation assurance is achieved by continuously providing pilots with traffic advisory information on the location of proximate and potentially threatening aircraft and by issuing resolution advisories on an as needed basis. In this way the safety of civil air traffic is enhanced while maintaining freedom of flight for the aviation community to the maximum extent possible.

ATARS services can be provided to all aircraft, controlled and uncontrolled, in both the en route and terminal environments. For those equipped for ATARS services, protection is provided against all aircraft that are equipped with altitude reporting transponders. Although resolution service cannot be provided against non-Mode C aircraft, traffic advisories will be provided to ATARS equipped aircraft on mode A and primary radar targets that are proximate in the horizontal plane. A single ATARS algorithm will be developed for application in both the en route and terminal environments; however, system thresholds and site adaptation parameters will depend on the individual installation. In addition, the deployment of the DABS/ATARS in the en route environment will utilize the back-to-back antenna to double the normal en route surveillance update rate thereby making it similar to that of the terminal system.

To receive ATARS service, an aircraft must carry a DABS transponder, an encoding altimeter and an ATARS display. The DABS transponder, in addition to its surveillance function, receives digital advisory messages from the ground and delivers them to the ATARS display for presentation to the pilot. The ground portion of the ATARS system consists of the DABS sensor which provides surveillance information and acts as a communications link to the aircraft, a computer which is independent of the existing air traffic control computer system, and interfaces to air traffic control facilities serving the airspace covered by the DABS sensor. (Figure 1)

Aircraft equipped for ATARS service will receive traffic advisories regarding aircraft that are determined to be proximate or to constitute a potential threat. In the case of a proximate aircraft, information will be displayed to alert the pilot concerning the presence of the nearby aircraft and to aid him in visual acquisition. When an aircraft poses a potential collision threat, that is when it violates the time to closest approach threshold (45-60 seconds) and the miss distance (1.2 nmi) threshold, additional information will be displayed to aid the pilot in threat assessment. The threat data will enable the pilot to evaluate the potential threat and to avoid maneuvers which would aggravate the situation. If the aircraft separation continues to narrow such that the time-to-closest-approach and the projected miss distance are less than the established command threshold (normally 20-30 seconds and 1.2 nmi respectively) for that region of airspace, then both of the aircraft will receive a resolution advisory. (In a controlled/uncontrolled encounter, the uncontrolled aircraft is issued the resolution advisory approximately 20 seconds before the controlled aircraft.) This

DABS/ATARS Concept

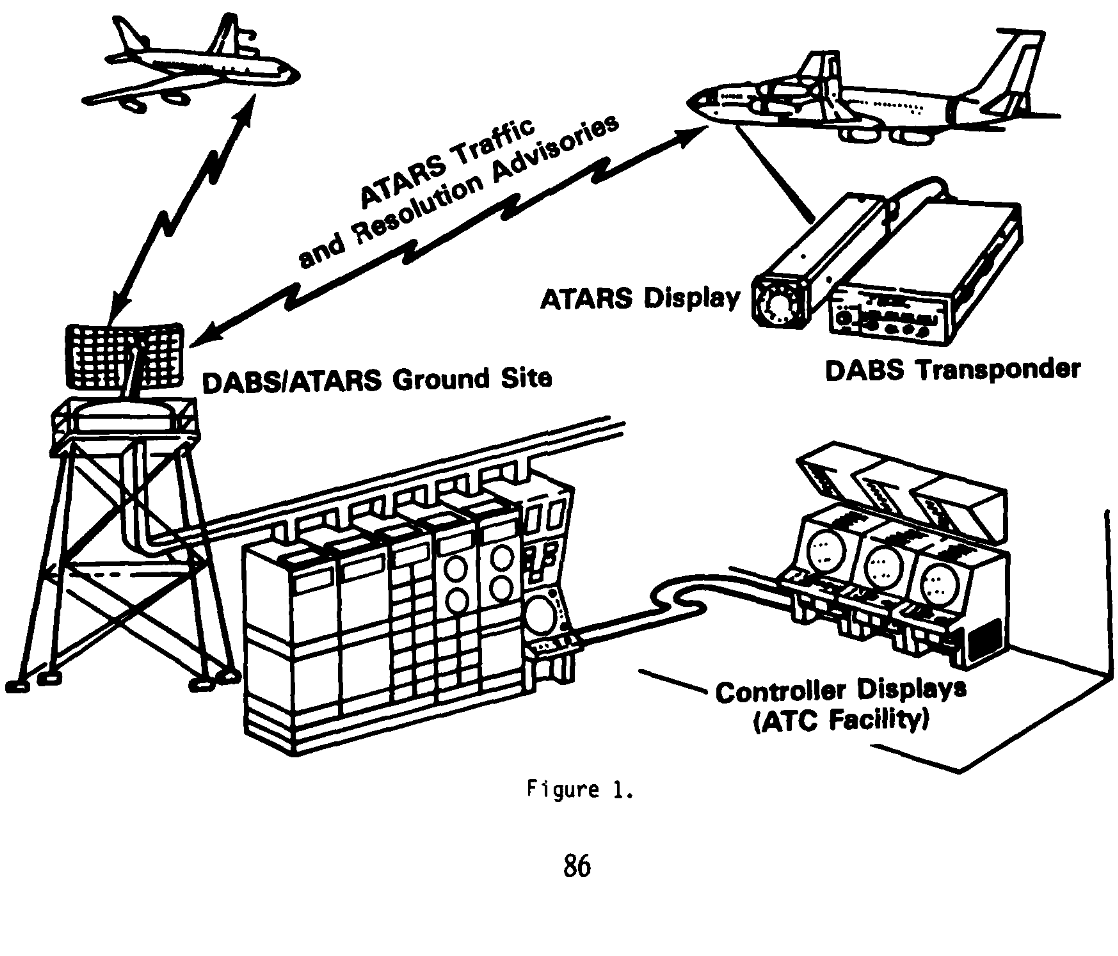

Figure 1.

resolution advisory will be compatible with the threat data provided in the traffic advisory.

Although ATARS will provide the same traffic advisory and resolution service to both controlled and uncontrolled aircraft, the manner in which it will be utilized by the pilot is expected to differ depending on the aircraft's control status. Since the pilot of the uncontrolled aircraft relies on see-and-avoid techniques as the principal method of maintaining separation, it is anticipated that he would utilize the traffic advisories to visually acquire proximate and potentially threatening aircraft and to determine whether or not they represent a real threat. Once the aircraft is visually acquired, the pilot could then mentally integrate the traffic advisory data with other factors to determine whether or not evasive actions need be taken. Although a goal of the traffic advisory service is to provide the pilot with sufficient information to enable him to maintain adequate separation in the absence of visual acquisition, the pilot may choose to delay evasive action until receipt of a resolution advisory if the threat aircraft is not visually acquired. In this way the traffic advisory service would provide increased aircraft safety by reducing the potential for midair collisions which may result from undetected traffic or optical illusions without imposing constraints on the pilot. The basic premise is that once the VFR pilot is made aware of a potential encounter and provided data concerning the threatening aircraft, the pilot can maintain adequate separation on his own.

In order to minimize pilot work load and air traffic control interaction, it is anticipated that controlled aircraft will rely more heavily on the resolution advisories rather than on the traffic advisories for determining the maneuver needed to resolve potential conflicts. In these cases, the traffic advisories would serve as a means for alerting the pilot to the details of the potential conflict and would prepare the pilot for the possibility of an escape maneuver if the potential conflict situation persists or worsens. Alerting the pilot to the specifics of the potential conflict would also serve to discourage independent maneuvers on the part of the pilot which could aggravate the situation.

Whenever a threat advisory is issued to a controlled aircraft, an ATARS controller alert message is sent to the air traffic control facility responsible for the controlled aircraft in order to alert the controller(s) to the potential conflict. This message will also include ATARS command preview data which will provide the controller with the command that ATARS would issue if it were to resolve the potential conflict at the time of the controller alert.

An ATARS resolution notice will be sent to the responsible air traffic control facility at the same time that the resolution advisory is sent to a controlled aircraft in conflict. The resolution notice will identify the aircraft involved in the conflict and the resolution advisories issued to each. Upon receipt, the air traffic control computer system will display these data to the responsible controller(s).

Technical Approach

The technical approach to ATARS development is to build upon the extensive body of knowledge gained during the evaluation of the IPC algorithm (Reference 3). The IPC evaluation program consisted of flight tests conducted by Lincoln Laboratory and ATC simulations conducted by NAFEC. The results of the IPC test and evaluation program have been documented in References 4, 5, 6, and 7.

In order to expedite the overall development and evaluation process, the ATARS algorithm will be developed in two stages called, the Interim ATARS algorithm and the Complete ATARS algorithm. The ATARS development process consists of three principal functional areas; namely,

(a) ATARS algorithm development.

(b) Development and integration of ATARS code into the DABS engineering models and the ATC Simulation Facility.

(c) Test and evaluation of ATARS at NAFEC.

The overall ATARS program schedule expressed in terms of the above functional areas is presented in Figure 2.

Description of the Interim ATARS Algorithm

The Interim ATARS algorithm will be described in terms of the modifications made to the IPC algorithm and the expected benefits resulting from the changes. These modifications fall into three areas, namely:

1. Changes to Data Link Message Construction to accommodate the expanded traffic advisory service,

2. Changes to Detection to incorporate the "Conflict Alert Emulator."

3. Changes to Master Resolution to improve resolution performance of the algorithm.

These changes are described in the paragraphs below.

ATARS Development Program Schedule

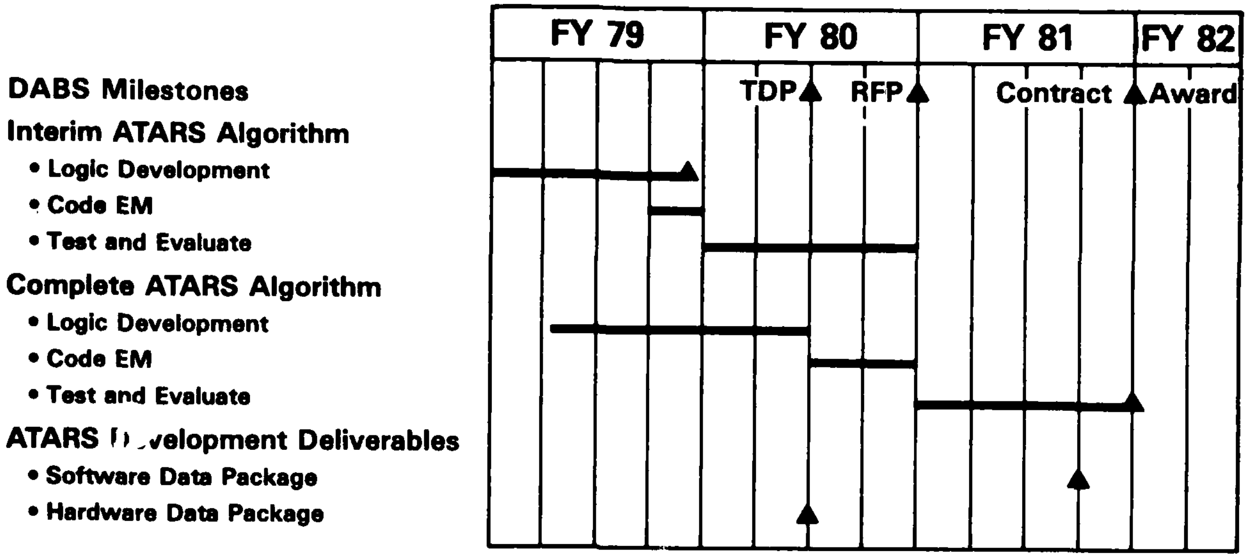

Figure 2.

<u>The Expanded Traffic Advisory Service.</u> Although the traffic advisory service of IPC (known as PWI or Proximity Warning Indicator) significantly enhanced visual acquisition performance and hence was found to be greatly appreciated by the pilot using see-and-avoid separation techniques, the subject pilots who flew the system expressed a desire for more complete information to further enhance visual acquisition and to aid in threat assessment.

A comprehensive traffic advisory service providing sufficient data on target aircraft to support both visual acquisition and threat assessment has been developed. It is expected to provide the following benefits:

1. It would make a significant contribution toward preventing midair collisions involving VFR aircraft without restricting freedom of flight.

2. By providing complete traffic advisory data early enough in the development of an encounter, including data to aid in threat assessment, the traffic advisory service would significantly reduce the probability of an aircraft maneuvering in a direction that would aggravate the potential conflict.

The ground-based portion of the traffic advisory service of ATARS will be enhanced to provide display-independent message formats to carry a complete set of traffic advisory data on the DABS data link. This will permit the traffic advisory service to be tailored, by means of a cockpit display unit, to meet the needs of various user groups. That is, the generalized message format will support a variety of displays ranging from a low cost general aviation unit to a sophisticated air carrier display. It is essential to the success of the program that ATARS be implementable by a low cost display in order to keep it within the economic reach of general aviation aircraft owners.

The expanded traffic advisory service will provide the following data on a target aircraft whenever the target satisfies the criteria for a proximity (non-threatening) advisory:

1. Bearing in 3.75 degree increments

2. Altitude in 100 foot increments

3. Range in 0.2 nmi increments

4. Coarse heading in 45 degree increments

5. Velocity in 10 knot increments

6. ATC control status

7. ATARS equippage

8. Abreviated aircraft descriptive data.

When the target aircraft is declared a threat, the following additional data is provided:

1. predicted miss distance in 0.2 nmi increments

2. vertical speed of threat in 200 FPM increments

3. fine heading in 2.8 degree increments

4. turning status of threat

Modifications to Detection. The detection portion of the algorithm has been modified to insure the compatibility of ATARS with the Conflict Alert function in the terminal ATC system. This is being accomplished by incorporating into ATARS the "Conflict Alert Emulator" which effectively constrains the issuance of an ATARS controller alert to coincide (or nearly coincide) with the conflict alert generated by the ARTS III computer. Threat advisories (flashing PWI's) are issued to the aircraft involved in a controlled/controlled or controlled/uncontrolled encounter at the same time that the ATARS controller alert is issued to the controlled aircraft. Fifteen seconds after the controller alert is issued, the command is issued to the uncontrolled aircraft (if one is required). Thirty-five seconds following the controller alert, the command is issued to the controlled aircraft. However, the command issuance time for controlled aircraft is further constrained to the interval between 20 and 30 seconds prior to closest approach.

Modifications to Master Resolution. The modifications made to improve the performance of the IPC resolution logic are provided below along with a description of the problem that the modification intends to resolve.

1. The "fixed rules" approach utilized in IPC master resolution will be replaced with an exhaustive search and command evaluation technique to select among all candidate single-plane and multi-plane maneuvers. For each set of candidate maneuvers, the ATARS processor "flies" each aircraft ahead in fast-time for the purpose of computing performance measures such as the achievable miss distance. The candidate maneuver sets are then rank ordered considering both technical performance as well as user oriented criteria. This exhaustive search approach is a major change to the IPC algorithm and is designed to eliminate most of the shortcomings discovered during flight testing of IPC. In particular, the problems that will be eliminated are:

   a. not selecting the best command

   b. instability of command selection at rule boundaries

   c. inadequate treatment of unequipped aircraft

   d. algorithm traps that prevented selection of desired commands

   e. resolution that would give rise to a return-to-course encounter

   f. excessive command duration

2. A turn sensing logic will be added to make ATARS more responsive to detecting maneuvers, especially in the terminal area. This capability, in conjunction with the exhaustive search technique, will significantly reduce the possibility of an existing turn being reversed.

3. A site adaptation logic will be added for the terminal area to reduce unnecessary ATARS interaction with the air traffic control system.

4. A logic for vertical speed limit commands as a substitute for vertical negative commands will be added in order to increase ATARS compatibility.

5. ATARS service will be extended to ranges beyond 90 nm by limiting the resolution advisories to the vertical plane and by increasing the lead time prior to closest approach at which resolution advisories are issued.

6. Protection against a dangerous maneuver by an unequipped proximate aircraft will be provided by the addition of logic to check for a threatening turn or altitude maneuver by the unequipped aircraft. This logic will provide for earlier detection of the conflict.

7. Reducing the number of unnecessary positive commands while providing protection against altitude clearance violations will be accomplished by eliminating the projection time in the calculation of vertical separation, and by reducing the immediate altitude threshold for positive commands.

8. Permitting horizontal commands for jet aircraft close to the airport will be accomplished by increasing the speed threshold.

9. In order to provide increased protection in certain special cases such as a DABS/ATCRBS encounter, double commands will be issued.

10. To prevent the issuance of unnecessary commands in cases of rapid vertical divergence, a special logic check will be added.

11. Command preview logic will be added. At the time a controller alert is declared, the resolution logic is called to determine the command that ATARS would give if it were issued at that time. This preview command is sent along with the controller alert message to indicate a candidate solution to the controller. When the ATARS algorithm calls for the

issuance of a command, the preview command will be tested using current track data to see if it will produce a safe miss distance. If so, it will be issued; if not, the command evaluation module will be reentered in search for the best command.

Description of the Complete ATARS Algorithm. The Complete ATARS Algorithm (Reference 8) will contain all the improvements embodied in the Interim algorithm plus the following additional features which are thought to be essential for an operational ATARS system. These additional features are:

1. A domino logic will be added to eliminate the possibility of resolution advisories causing chain reactions; i.e., secondary encounters.

2. The multi-aircraft logic will be improved to effectively handle situations when chain reactions would be unavoidable with two-aircraft logic.

3. Epoch based multi-site coordination logic will be replaced by a sector-based multi-site coordination logic along with a through-the-transponder coordination logic to reduce the site-to-site communications requirement for DABS/ATARS and, therefore the operational cost of DABS/ATARS netting.

4. A logic for terrain, obstacle and restricted airspace avoidance will be added.

5. Logic will be added to insure that ATARS and BCAS function compatibly.

6. Logic will be added to insure that ATARS functions properly in the same area between an en route and terminal ATARS.

7. The ATARS/ATC system interface logic (Conflict Alert Emulator) will be extended to emulate the conflict alert with respect to proximate target (PROCON) and maneuvering target (MFMANS) alerts.

There are two enhancements to the Complete ATARS algorithm currently being planned. The first will permit ATARS to provide a reduced capability proximity advisory on target aircraft that are not mode C equipped, that is, ATCRBS mode A and primary radar targets.

The second is principally an enhancement to DABS surveillance to provide accurate surveillance data in the presence of diffracting objects. A multi-lateration technique using surveillance data from remote DABS sensors will be employed to significantly improve surveillance and tracking of aircraft in the vicinity of known diffracting objects.

ATARS Test and Evaluation. The ATARS Test and Evaluation Program is structured to expedite the overall evaluation of ATARS. This is accomplished by testing the Interim ATARS algorithm as soon as it is available in all the aspects that are not scheduled to be affected by the evolution to the Complete ATARS algorithm. Although Complete ATARS is the version of the algorithm which is to be delivered to the operating services for implementation, the Interim algorithm has the same basic modules for detection, master resolution, and traffic advisories as does the Complete ATARS algorithm.

The Interim ATARS algorithm retains the structure and epoch processing multi-site coordination techniques of the IPC algorithm; but it contains substantial changes to detection and a complete rework of the master resolution portion of the original algorithm. The changes to detection are designed to make ATARS compatible with the Conflict Alert function resident in the terminal ATC computer. In particular, the timing of the ATARS controller alert is being modelled after the linear predictor portion of Conflict Alert and the ATARS site adaptation is being modelled after Conflict Alert adaptation. For this reason, this change is being referred to as the "conflict alert emulator." This will enable ATARS to produce it's controller alert at approximately the same time (within one 4 second scan) as the ATC computer's conflict alert.

The Complete ATARS algorithm will contain the same detection and resolution logic found in the Interim algorithn, but the structure of the algorithm will be completely different due to the change from epoch to sector processing. The Complete ATARS algorithm also contains an improved multi-aircraft logic as well as the additional features/functions previously described.

The test and evaluation of ATARS consists of both a technial evaluation and an operational evaluation. The technical evauation of ATARS will be conducted for both the Interim and Complete Algorithm in the following major areas:

1. Hardware capacity

2. Resolution logic

3. Detection logic (alarm rates)

4. ATC compatibility

5. Multi-site coordination

6. Subjective (pilot) evaluation of ATARS

Hardware Capacity Evaluation. The principal purpose of this effort is to estimate the ATARS hardware capacity required to implement Complete ATARS. An initial hardware estimate will be made available at the time the DABS single site TDP is delivered (4/80). This initial estimate will be updated in 6/81 at which time the Computer Program Functional Specification (CPFS) for Complete ATARS will be delivered to the operating service.

The approach taken is to analyze the capacity of the DABS/ATARS engineering model (EM) at NAFEC as implemented by Texas Instruments (TI) with both the IPC and the Interim ATARS algorithms. The results of this analysis will be used to develop an ATARS capacity model which will then be employed to estimate the hardware capacity required to implement Complete ATARS and its enhancements. When the Complete ATARS algorithm becomes available it will be integrated into the EM and analyzed through capacity testing to provide an update to the 4/80 hardware estimate.

The available capacity of the DABS/ATARS EM will be explored using two configurations. One configuration will employ an ATARS capacity driver which will accept as input capacity traffic scenarios and output target data to the ATARS portion of DABS/ATARS EM in a format identical to that of DABS. The capacity driver, therefore, acts as a DABS emulator.

The second configuration will employ the Aircraft Reply Interference Environmental Simulator (ARIES) to translate ıpacity traffic scenarios into inputs to the DABS/ATARS EM.

The first configuration will be used to determine and analyze the capacity limitations of the ATARS hardware implementation independent of DABS while the second configuration is required to understand the interaction of DABS and ATARS under varying capacity loads.

Both configurations will be exercised with a family of traffic scenarios expressly developed to determine the relationship of key performance measures to changes in the traffic load. A computer performance measurement system consisting of a minicomputer coupled to both hardware probes and software hooks is being developed to provide the detailed and quantitative data required for the capacity analysis and subsequent modeling effort.

Resolution Logic Evaluation. The capabilities and limitations of the ATARS resolution logic will be evaluated in detail using four independent test beds; namely

(a) MITRE Monte-Carlo (fast time) Simulation Vehicle,

(b) Fast-time ATARS simulator at NAFEC,

(c) The ATARS portion of the DABS/ATARS EM at NAFEC driven by the real-time responsive simulator,

(d) The DABS/ATARS EM at NAFEC providing collision avoidance services to test aircraft that are involved in collision, near collision and safe passage encounters.

These test beds will be exercised with both the Interim and Complete ATARS algorithm; however, the bulk of the performance data on the ATARS resolution logic is expected to come from the evaluation of the Interim logic since it contains the great majority of the Complete ATARS modifications designed to improve resolution performance.

The fast-time simulators generate DABS like target reports derived from the encounter scenarios provided as an input and presents them to the ATARS detection and resolution logic being tested. They also maneuver the aircraft in response to ATARS commands thereby permitting the effectiveness of the logic to be determined. The encounters that make up the data base for the fast-time evaluations include:

(a) the 15 NTSB documented midair collisions,

(b) all the encounters from the Lincoln Laboratory flight tests that proved to be problems for the original IPC algorithm,

(c) other single and multi-aircraft encounters selected to determine the algorithm's capabilities and limitations.

The evaluation of the resolution logic with the responsive simulator will be conducted in real-time with the ATARS computers that are contained in the EM at NAFEC. The responsive simulator evaluation will be used to debug the EM code and to screen encounters being considered for flight testing.

The flight test program will be conducted at NAFEC with a limited subset of the encounters used in the fast-time and real-time simulations. The principal purpose for flight testing the resolution logic is to validate the extensive simulation results rather than duplicate all of them.

Detection Logic (Alarm Rate) Evaluation. The detection logic will be evaluated to determine its behavior under abnormal and normal conditions, that is,

(a) when aircraft become envolved in a near collision or collision encounter, and

(b) when aircraft are flying in accordance with ATC procedures and are safely separated.

The performance of the detection logic in the abnormal environment will be determined through extensive testing with the real-time and fast-time simulation test beds previously described. In particular, the behavior of the detection logic will be analyzed and characterized for each of the encounter scenarios created for use with the Monte-Carlo and Engineering Model simulators.

To determine the behavior of the detection logic in the normal operating environment, a data base consisting of representative traffic sample will be employed to exercise the logic. This data base is comprised of the following:

(a) Traffic tapes from terminal ATC facilities (ARTS tapes)

  (1) 3 hours from Philadelphia

  (2) 3 hours from Washington

  (3) 1 hour from Los Angeles

  (4) 64 hours from Houston

(b) Traffic tapes from en oute ATC facilities (SAR tapes)

  (1) 4 hours from the Washington Center

(c) Traffic tapes obtained by Lincoln Laboratory using the Transportable Measurement Facility (TMF) which employed the DABS monopulse and signal processing capability. This data was originally collected to support the verification of DABS sensor surveillance performance (ATCRBS mode) at typical ASR sites throughout CONUS.

  (1) 18 hours from the Boston terminal area

  (2) 10 hours from the Washington terminal area

  (3) 11 hours from the Los Angeles terminal area

(d) Actual traffic processed by the DABS/ATARS engineering models at Clementon, NJ (Philadelphia terminal area) and Elwood, NJ (en route sensor) over an extended period of time.

The processing of the ARTS and SAR tapes will be accomplished in the MITRE Monte-Carlo Simulation Vehicle. The Interim algorithm will be exercised using the 64 hours of Houston data while the Complete algorithm will evaluate against all of the ARTS and SAR data available. Since the ATARS logic for determining proximate targets is identical to the IPC Ordinary Proximity Warning Indicator (OPWI) logic, results obtained from the analyses of OPWI's are directly applicable. Reference 9 presents a characterization of proximity advisories in the Philadelphia, Washington, and Los Angeles terminal areas and the Washington en route airspace.

NAFEC is developing a technique for interfacing the TMF tapes with the DABS/ATARS EM at NAFEC. Once completed, the EM will be used to process the TMF traffic samples with the Interim Algorithm and record data appropriate for the analyses of ATARS alarms.

Both long and short term statistics will be compiled at NAFEC on the alarms generated by the DABS/ATARS systems with the Interim algorithm located at Clementon and Elwood.

ATC Compatibility Evaluation. The initial ATC compatibility evaluation of ATARS will be conducted using the Air Traffic Control Simulation Facility (ATCSF) at NAFEC in a stand-alone mode. A more comprehensive evaluation of ATARS-ATC compatibility is described as an element of the operational evaluation.

The type and level of ATC interaction produced by the Interim ATARS algorithm operating in the Philadelphia terminal environment will be investigated. The results will be analyzed in detail to develop refinements to the algorithm in order to insure its compatibility with ATC operational procedures in a terminal environment. Refinements are anticipated to the ATARS site adaptation technique as well as to the detection portion of the algorithm.

The ATC compatibility evaluation will be conducted in two phases. Phase I will utilize Philadelphia traffic tapes from the Clementon sensor or from previous ATCSF experiments of the Philadelphia environment in a fast-time simulation to examine the conditions under which alarms are being generated for the purpose of optimizing detection and site adaptation parameters. Phase II will use field controllers in a real-time ATC simulation to control the simulated traffic according to current Philadelphia control procedures.

Multi-Site Coordination Evaluation. Evaluating the multi-site aspects of the Complete ATARS algorithm will be accomplished using the following two independent test beds:

1. Multi-site simulation using the MITRE IBM 370 computer system,

2. The DABS/ATARS engineering models located at Clementon, Elwood and NAFEC.

Following its development, the MITRE multi-site simulation will be utilized to investigate the performance of the algorithm with respect to the following:

1. coordination between 2 and 3 sites,

2. failure modes in site-to-site coordination,

3. through-the-transponder coordination technique and its operation with and without ground coordination line,

4. ATARS-BCAS interface.

The three DABS/ATARS engineering models will be netted together to support flight tests that are designed to exercise the multi-site portions of the algorithm.

Subjective (Pilot) Evaluation of ATARS. An evaluation of ATARS from the pilots point of view will be made by conducting a flight test program within coverage of the DABS/ATARS

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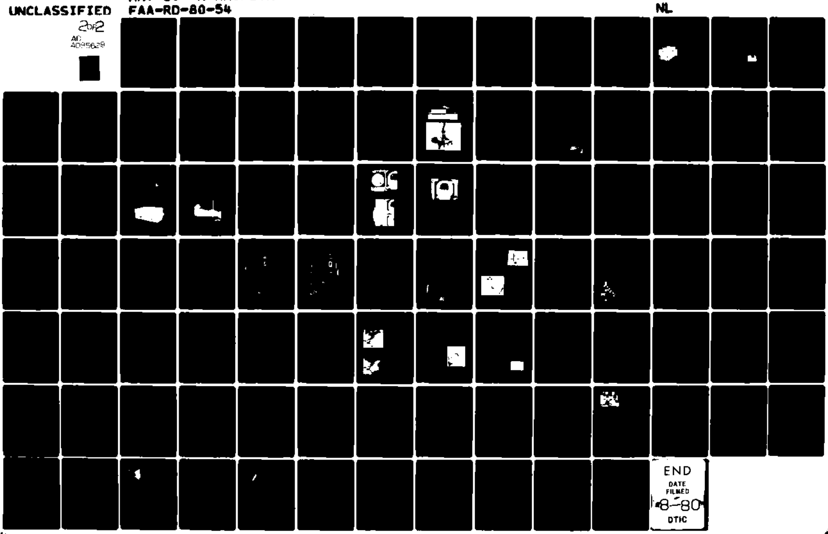

engineering models. Subject pilots and test pilots will fly ATARS equipped aircraft to determine pilot acceptance of the traffic and resolution advisories being presented by ATARS. Pilot evaluation will be solicited from flights of planned conflicts as well as from flights through the Philadelphia terminal environment that are likely to generate some ATARS traffic advisory activity.

The flight test aircraft will be equipped with a micro-processor-based display system that can be programmed to implement a variety of display operating concepts. The micro-processor will be interfaced with an air carrier or general aviation display, and a cockpit speaker for enunciating the receipt of traffic or resolution advisories. The color CRT used in the Bendix color weather radar will be used as the display representative of the sophisticated application (such as air carrier) while a smaller, lower cost display will be utilized as representative of the general aviation application.

The flight test program will focus on assessing the effectiveness of the traffic advisory service and the compatibility of the traffic advisory service with the resolution service. In particular, the planned assessment will include the following:

1. Evaluate improvement to pilot's visual acquisition performance as a function of information provided,

2. Evaluate threat assessment capability of pilot using traffic advisory service,

   (a) Determine relationship of traffic advisories to resolution advisories,

   (b) Assess value of traffic advisory service as a precursor to resolution advisories,

   (c) Determine how pilots use ATARS and compare to FAA's planned use of ATARS,

   (d) Determine value of information contained in the traffic advisory service messages,

   (e) Determine pilot's reliance on display with and without visual acquisition when receiving proximate or threat advisories,

   (f) Determine time required by pilot to effectively use traffic advisory,

   (g) Determine pilot's capability to make an accurate threat assessment before the resolution advisory is displayed,

   (h) Determine pilot's response to traffic advisory service
      - maneuver prior to resolution advisory
      - contact ATC
      - with and without visual acquisition,

   (i) Determine pilot concurrence with threat advisory when threat has been visually acquired.

3. Evaluate pilot's response to resolution advisories

   (a) Determine pilot concurrence with resolution advisories

   (b) Determine willingness of pilots to follow resolution advisories
      - with and without traffic advisory service
      - with and without visual acquisition.

<u>Operational Evaluation and Demonstration.</u> The operational evaluation of ATARS will consist of the following tests and demonstrations conducted with the complete ATARS algorithm:

1. ATC system tests conducted at NAFEC using the Terminal Automation Test Facility (TATF) and the System Support Facility (SSF)

2. Demonstration flights at NAFEC and in the Philadelphia terminal environment,

3. Long term alarm rate data from the Clementon and Elwood DABS/ATARS systems,

4. Pre-operational user demonstration consisting of user owned ATARS equipped aircraft operating in the Philadelphia terminal environment.

The TATF and SSF will be employed to conduct operational evaluations of the Complete ATARS Algorithm in the terminal and en route environments respectively. For these evaluations the Air Traffic Control Simulation Facility (ATCSF) will be used to generate traffic and to maneuver aircraft in response to controller instructions or ATARS resolution advisories. In the principal configuration selected for evaluation, the ATCSF will also emulate DABS and ATARS, and therefore will interface with the TATF (and SSF). In the validation configuration, the DABS/ATARS EM at NAFEC is interfaced with the TATF (and SSF) while the ATCSF is interfaced with ARIES as the method of providing target reports into the EM.

Four candidate modes for operating ATARS in the terminal environment have been selected for evaluations. These modes will be exercised in both the Philadelphia and Atlanta terminal environments:

1. To identify changes to ATC procedures resulting from the presence of ATARS in the traffic control environment.

2. To evaluate possible controller use of ATARS-generated collision avoidance information.

3. To examine the interaction of ATARS-generated collision avoidance information with the Conflict Alert (CA) and Minimum Safe Altitude Warning (MSAW) functions in the Terminal Area ATC system.

4. To describe the modifications to Terminal ATC software necessary to accomodate its interace with ATARS.

A more complete description of the ATC system test for the terminal environment can be found in the ATC test guidance document prepared for those tests (Reference 10).

The test beds for the demonstration flights and the long term alarm rate determination are the same as those described for the technical evaluation of alarm rates except that here the final version of the ATARS algorithm will be used.

There are tentative plans to conduct an extended preoperational user demonstration in the Philadelphia terminal environment. This will be accomplished by equipping approximately a dozen user owned aircraft with prototype DABS/ATARS avionics provided by the government. Aircraft will be selected for participation in order to maximize exposure to DABS and ATARS. Aircraft belonging to commuter airlines, flying clubs and fixed base operators are probable candidates.

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BEACON COLLISION AVOIDANCE SYSTEM (BCAS)

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Biography

Mr. McIntire is Chief of the Full Beacon Collision Avoidance System Section. Separation Systems Branch, Communications and Surveillance Division. He received his BSEE in 1948 and BSADME in 1949 from Tri-State College. He worked as an engineering leader with Hazeltine, Corporation in Indianapolis, Indiana during a break in employment with the FAA. Mr. McIntire joined the CAA in 1951.

ABSTRACT

The Beacon Collision Avoidance System (BCAS) is an airborne collision avoidance system offering separation assurance and data link services among equipped aircraft. Advanced features of the Discrete Address Beacon System (DABS) are used in the BCAS design to achieve surveillance of intruder aircraft and data-linking to communicate air-to-air and air-to-ground. The principal objective of the BCAS program is to enhance the safety of air travel by reducing the potential for midair collisions. It will be compatible with the primary means of aircraft separation - the ground based ATC system.

BCAS is being developed in two stages. The first stage of development will produce a system of limited capacity that will issue vertical collision avoidance commands to the pilot. The second stage of development will provide a high capacity system that will enhance the pilots see-and-avoid capability and adds the flexibility of horizontal maneuvers.

INTRODUCTION

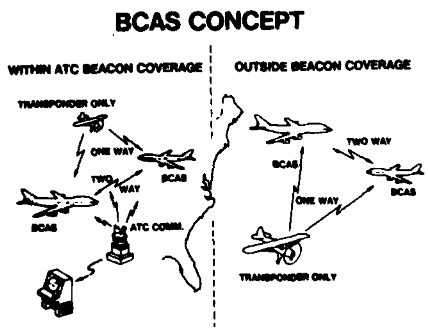
The Beacon Collision Avoidance System (BCAS) is an airborne collision system offering separation assurance and data link services among equipped aircraft. BCAS is a cooperative system that capitalizes on the existing large investment in secondary surveillance radar (SSR) transponders to achieve effective separation assurance with the very first BCAS installation. Advanced features of the Discrete Address Beacon System (DABS) are utilized in the BCAS to achieve resolution of potential collisions with both the intruder and Air Traffic Control (ATC).

The principal objective of the BCAS program is to enhance the safety of air travel by reducing the potential for midair collisions. Supplemental protection will be afforded aircraft operating inside coverage of the ground based ATC system and primary protection will be provided to aircraft outside ATC system coverage. At the same time, BCAS will be compatible with the primary means of aircraft separation - the ground based ATC system.

Two BCAS systems are under development. One system is a BCAS that operates in low to medium density traffic and provides vertical maneuver commands to the pilot. The second BCAS is a more complex system capable of operation in high density traffic and enhances the pilots ability to operate in the "see-and-avoid" environment. In addition, the flexibility of horizontal maneuvers is available.

BCAS must be acceptable to the pilot as well as compatible with ATC. This means that BCAS must be capable of providing safe separation while maintaining a low false alarm rate.

BCAS is a concept (see Figure 1) for an



airborne Collision Avoidance System (CAS) based on the use of replies transmitted by the Air Traffic Control Radar Beacon System (ATCRBS) transponders or the future Discrete Address Beacon System (DABS) transponder.

Of the two versions of BCAS under development, Active BCAS is the simpler. Active BCAS is essentially an airborne interrogator, soliciting replies from other transponder equipped aircraft in communication range. The time between interrogation and reply is measured to determine intruder range.

Altitude is determined by decoding the intruder Mode C transponder replies. By differentiating this data, closing range-rate and altitude rate are determined and used to select vertical escape maneuvers when the threat evaluation logic determines that a collision threat exists.

Since Active BCAS uses an omnidirectional antenna, all ATCRBS transponder equipped aircraft in communication range reply to each interrogation. To reduce the number of replies, and hence synchronous garble, an adaptation of the side lobe suppression circuitry used by ATCRBS interrogators has been developed. This adaptation is called Whisper-Shout and is a means of grouping targets generally in accordance to their range from the airborne interrogator. Aircraft are first interrogated at a low power level (the Whisper), picking up near and very sensitive receiver target(s). Once these targets have replied, they are suppressed. During this suppression period, nominally 35 usec, a second interrogation is transmitted at a higher power level to pick up more targets. This procedure is repeated 3 to 4 times, with the last interrogation (the shout) at full power, insuring that all targets have been interrogated.

In addition to the Whisper-Shout technique, directional antennas are being studied. Such antennas may further reduce synchronous garble through directional interrogate and receive functions which limit the processing load to relatively few aircraft. Other advantages also accrue from the use of directional antennas. By using monopulse detection techniques, the relative bearing to other aircraft can be theoretically obtained to within 10 degrees using the antenna now under consideration. Such bearing accuracy would enable Active BCAS to provide Proximity Warning Information (PWI). PWI will in some cases permit a pilot to visually acquire other aircraft during VFR weather but will, in any weather, provide an alert that other traffic is near.

Active BCAS DABS interrogations are based on the discrete address transmitted via "squitter messages from DABS equipped aircraft within communications range. Squitter messages are spontaneous - occurring approximately once per second - and, in addition to making the intruder's DABS discrete address known to the BCAS interrogators, provides relative altitude information. BCAS equipped aircraft use the squitter altitude report to determine if the target aircraft poses a potential hazard and, if so, uses the discrete address for the DABS interrogation. No other aircraft reply to the discrete interrogation, thereby reducing fruit and garble.

The second version of BCAS (Full BCAS) is a full capability system that incorporates the features of Active BCAS as one mode of operation. Full BCAS also has passive and semi-active modes. In the Passive mode, Full BCAS "listens" to ground interrogations and the subsequent airborne replies, and thus does not contribute fruit or garble to the environment. In addition, Full BCAS obtains as a minimum: (1) the interrogation repetition frequency of the ground radar site, and (2) the bearing of the ground radar site relative to the heading of the BCAS equipped aircraft. This information can be obtained by Full BCAS without any modification to the ground radar site using the BCAS phased array antenna. However, it is desirable that radar-based transponders (RBX's) be installed at ATCRBS sites to enable a Full BCAS aircraft to obtain more accurate ATCRBS site information such as site altitude, more accurate relative bearing, and to determine its range to the ATCRBS site. The RBX presence also allows for a data link interface with ATC.

Full BCAS cannot always operate passively, even when there is ground surveillance coverage. In particular, BCAS performance can vary dramatically as a function of the relative positions of the ground interrogators, the BCAS aircraft, and the target. Certain passive modes of operation have regions in which position errors tend to become unacceptably large. When such singularities occur or when the position error in the passive mode solution is too large, a semi-active mode of Full BCAS must be employed in order to provide acceptable BCAS performance. Semi-active means use of data from both the passive and active modes of operation. Thus, BCAS will obtain data actively, passively or semi-actively, depending on the environment. These data can be obtained in an ATCRBS or DABS environment with the total system performance improving as the ATCRBS undergoes a transition to DABS (fruit and garble levels are reduced).

Once potential conflicts have been detected, BCAS issues the appropriate warnings based on its tracking data. When both aircraft are BCAS equipped, the maneuvers are coordinated through the use of the DABS data link. Thus, complementary maneuvers are assured. If the target aircraft is not BCAS equipped, maneuvers are based on the assumption that no change in its present course will occur.

TECHNICAL APPROACH

The BCAS development program is structured to be accomplished in three phases.

Phase I - Feasibility Demonstration: - The Phase I effort involved two parts. The first part of Phase I was an initial analysis of the BCAS operational environment (e.g., traffic models, peak densities, and ATCRBS/DABS surveillance performance) and ATC operational capability to the degree sufficient to assess the technical feasibility of BCAS.

The second part of Phase I was the design and fabrication of feasibility models of BCAS sufficient to independently demonstrate the feasibility of the active, passive and semi-active modes. Efforts under Phase I are complete.

Phase II - Engineering Development: - Under Phase II, the feasibility models of the active and passive modes fabricated under Phase I were upgraded to include the functional capability deemed necessary for operational BCAS systems. In addition, the DABS mode experimental model was used to assess active operation in a DABS environment.

Phase II - Prototype Development and Operational Tests:

The objective of this phase is to verify the operational suitability of BCAS and to publish appropriate standards.

Field tests will confirm the utility of BCAS operation, determine the phenomena that limit performance, and characterize the related environment. These tests of BCAS will involve installation of prototype equipments on operational FAA and air carrier aircraft for evaluation in the operational environment.

Active BCAS

Current Phase II and III activities in the Active BCAS Program areas revolve around the three activities described below.

(1) Design and fabrication of engineering models at Lincoln Laboratory to include basic units employing omnidirectional antennas, a unit augmented with directional antennas for PWI and a unit specifically designed for use on general aviation aircraft.

(2) Design and fabrication of prototype units by industry for installation and evaluation on air carrier aircraft.

(3) Test and evaluation of the Active BCAS concept to include:

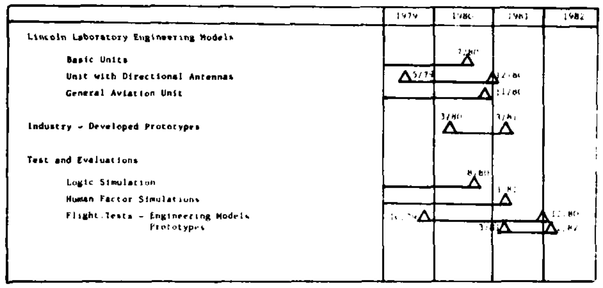
(a) Computer simulations of threat detection and resolution logic performance,

(b) Human factors simulations of Active BCAS operational impact in the cockpit and in ATC facilities, and

(c) Flight tests of engineering models and prototype units in both controlled and operational environments.

Figure C-1 shows the schedule for these activities.

Figure C-1. Active BCAS Program Schedule



Full BCAS

The Full BCAS Program is based on a three-task industry development as follows:

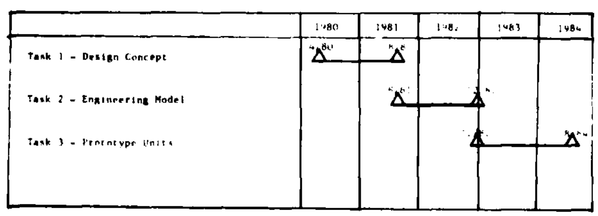
(a) Task I - Two contractors will develop design concepts in accordance with FAA performance requirements. These concepts will be evaluated on a simulation test bed at NAFEC.

(b) Task II - One of the Task I contractors will be selected to fabricate engineering models based on their Task I design concept. These models will be evaluated by flight testing at NAFEC.

(c) Task III - The Task II contractor will fabricate several prototypes. These units will be evaluated in air carrier aircraft in the operational environment.

Figure C-2 shows the schedule for the three Full BCAS Program Tasks.

Figure C-2. Full BCAS Program Schedule



PROGRAM PROGRESS

Active BCAS

The design and fabrication of engineering models at Lincoln Laboratory has generated very encouraging results with regard to the potential performance of the Active BCAS concept. While these units have not been completed, the testing of signal processing techniques and assemblies associated with Active BCAS indicate that intruder tracking should be highly reliable with the false alarm rate well within acceptable bounds.

A request for proposals to design and fabricate industry prototypes was released in August 1979 and proposals were received in October. The technical evaluation was completed in November and awards are anticipated in early 1980.

Computer simulations of the threat detection and resolution logic have continued along with real-time human factors studies associated with both the pilot and the controller interfaces. These studies have generated logic refinements that will enhance the operational utility and acceptability of Active BCAS.

Full BCAS

The FAA published its Full BCAS Concept Report which describes the system in considerable detail. This document and an associated engineering requirement which specifies minimum acceptable performance levels provided the basis for requests for proposals to perform the three-task industry proposal. Proposals were received in July and the technical evaluation were completed in December. Contract awards are expected in early 1980.

APPENDIX

Reports of 1979 activities supporting development of a BCAS system are as follows:

Separation Assurance Development Status Reports

"BCAS Industry Briefing" (Presented at Lincoln Laboratory), February 1979.

"Aircraft Separation Assurance Technical Developments" submitted to the Subcommite on Transportation, Aviation, and Communications, Committee on Science and Technology House of Representatives, February 1979

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Blake, N.A., et al. "Report of the FAA Task Force on Aircraft Separation Assurance," FAA-EM-78-19, Volume I, II, & III, December 1978

Koenke, E.J., et al. "FAA BCAS Concept," FAA-EM-78-5, Volume I, II, & III, April 1978

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Lincoln Laboratory, "Beacon Collision Avoidance System" Quarterly Technical Letter, BCAS QTL-4-10, May 1979

Lincoln Laboratory, "Beacon Collision Avoidance System" Quarterly Technical Letter, BCAS QTL-4-11, July 1979

Lincoln Laboratory, "Beacon Collision Avoidance System" Quarterly Technical Letter, BCAS QTL-4-12

AIRPORT SECURITY SYSTEMS DEVELOPMENTS
BOMB AND EXPLOSIVES DETECTION

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BIOGRAPHY

Gerald Carp is the Chief of the Voice and Security Systems Branch responsible for research and development in aviation security. He received his BEE from CCNY and his MEE from the Polytechnic Institute of Brooklyn. Before joining the FAA in 1977, he spent two years teaching electrical engineering at City College, ten years as Chief of the Radiation Effects Branch at ECOM doing research on nuclear weapons effects, eight years with the General Electric Company designing major systems for detection of nuclear detonation, two years with the General Learning Corporation as Director of Advanced Development responsible for applying modern technology to the educational process, six years with the MITRE Corporation where he was responsible for the design and development of unattended ground sensors for military applications and two years with the Drug Enforcement Administration as Chief of the Advanced Technology Branch.

ABSTRACT

This paper reviews the current state-of-the-art of bomb detection, identification, and neutralization techniques applicable to airport and aircraft safety. Primary emphasis is placed upon the efforts supported by the Federal Aviation Administration (FAA) and the requirement that these systems be usable in the commercial aviation environment. Among the FAA programs described are the development of detection systems based upon thermal neutron activation, automated X-ray image recognition, nuclear magnetic resonance, and macrosmatic animals. The specific approaches and performance of these systems are given along with a description of planned R&D programs designed to develop improved techniques and systems for aviation security.

A new concept, deactivation "tagging" of explosives by the addition of special materials during manufacture, which seeks to neutralize or sterilize bombs during routine screening operations, is described and candidate means of accomplishing deactivation are presented.

INTRODUCTION

The Federal Aviation Administration (FAA) is confronted with a number of security problems which present challenges and opportunities to the technical and industrial community. All airline travelers are aware of the security screening, metal detectors and imaging X-ray systems used for antihijacking and sabotage prevention. This program has been successful. In 1979, none of the six hijacking attempts of United States (US) air carriers occurred because of a real weapon or a high explosive penetrating the screening system; there was however one bombing. Since January 1973, when mandatory screening was implemented, there have been only 31 attempted hijackings of US airlines. Of these, only three were successful, and none involved smuggling of weapons through a screening station. During this period, more than two billion passengers and three billion pieces of luggage were screened.

The most challenging current problem, the one receiving a great deal of FAA attention, is the detection of bombs in checked luggage and air cargo. Current approaches to bomb detection are based on the measurement of natural unique vapors or components. Alternatively, detection may be approached by the use of taggants, special materials added during the manufacturing processes to aid in the detection of explosives. Also under consideration is deactivation "tagging", the addition of special materials during manufacture which will permit neutralization or sterilization of bombs during routine screening operations.

Although there are many US requirements for bomb detection systems, this paper will emphasize the FAA requirements and programs. The FAA program emphasizes the detection of untagged explosives; other federal agencies' programs emphasize tagging-based systems. Following is a description of the required screening system peformance characteristics, current R&D programs for bomb detection sytems, and new approaches under consideration.

FAA Bomb Detection System Requirements

To place the FAA program into perspective, I will first review the environment in which an explosive screening system must technically and economically operate.

First, some US statistics for 1978:

	US	FOREIGN	TOTAL
carriers	36	72	108
airports	450	168*	618
aircraft	2,600	-	2,600
enplanements per day	747,500	40,000	787,500
passenger checked bags per day	1,300,000	70,000	1,370,000
carry-on item per day	1,020,000	58,000	1,028,000
air cargo	5.7 million tons		

*Served by US carrier and/or final departure point for foreign carrier flights to the US.

The Foreign column represents service to and from the US by foreign carriers. Further, the security system must not only be capable of handling the current passenger enplanements but also the projected growth to some 300 million per year in 1982 and 400 million per year by 1989. Although there are 900 air carrier airports, about 45 carry well over 80 percent of the traffic. Thus, the security screening systems being developed are primarily aimed at these high volume airports such as O'Hare, Chicago; John F. Kennedy, New York; and Los Angeles International, California. The smaller feeder airports can employ simpler (less expensive) hand search techniques.

The constraints under which the system must operate are:

- The flow of people and baggage should not be inhibited in a manner which could create unwarranted delays.
- The system must be reliable, easily maintained and operable by relatively untrained personnel.
- The system should not present a safety hazard or otherwise be harmful to the environment.
- The system should not damage the contents of luggage in any way, nor present an invasion of privacy.
- The system/procedures should not present an unwarranted financial burden to the airlines, airport owners, or passengers.

The critical parameters of a screening system are:

- Throughput - The average rate at which checked luggage can be screened; studies indicate a minimum of 10 bags per minute is required.
- Detection Rate - While 100 percent is desirable, a somewhat lower rate would still create an unacceptable risk to a would be bomber. The FAA currently feels that a 90 percent detection rate will provide a credible deterrent.
- False Alarm Rate - Given that adequate detection and inspection rates are achieved, system operating cost is highly sensitive to false alarm rate. In any system, all alarms must be treated as real alarms until proven otherwise. No bomb detection system can treat an alarm casually. Yet, evoking a full explosive ordinance disposal (EOD) response to an alarm is both costly and time consuming. An alarm rate as low as one percent would, in the US, involve some five million bags per year, or approximately six bags per fully loaded 747 aircraft. With the unlimited variety of contents "normal" to passenger baggage (we have encountered some 30 pounds of three foot long screwdrivers in one suitcase, several large salamies and cheeses in another, and candelabrum in still another), maintaining the necessary detection and throughput rates with acceptable false alarm rates is the most challenging problem facing bomb detection system designers.

CURRENT R&D PROGRAMS

Current FAA bomb detection R&D programs are directed at the detection of normal or natural explosives rather than tagged explosives. Tagging, which involves the addition of some material with unique properties to the explosive during manufacture, is being actively pursued by the Bureau of Alcohol, Tobacco and Firearms (ATF).[1] Enabling legislation (S.2013) requiring the addition of taggants into all legal non-military explosives manufactured or imported into the US is being considered by the 95th Congress. The FAA emphasis on untagged detection avoids duplication of effort with ATF and also addresses explosive security for US airlines in countries where untagged explosives may be a threat.

Vapor Detection Programs

Vapor detection programs are based upon the presence of one or more vapors unique to each explosive. The existence of such vapors has been demonstrated by the performance of specially trained dogs which have detected explosives at rates on the order of 90 percent. Unfortunately, dogs require handlers and the team, while effective, is too costly for routine screening. Electronic explosive vapor detectors such as the electron capture devices currently on the market can readily detect nitro- based dynamite but do not respond to C-4 and some other explosives. Unfortunately, most electron capture devices also respond to many other substances such as shaving lotion, shoe polish, etc., which are commonly found in luggage and airport environments. Moreover, their typical sensitivity, of the order of 1 part in 10^9, is inadequate for effective operational use.[2] In general, none of the currently available commercial explosive vapor sensors meet operational airport use requirements.

Explosive Vapor Characterization

IIT Research Institute, Chicago, Illinois

The objectives of this program include identification and measurements of partial vapor pressures of substances and their degradation products that might be used to characterize explosives of interest and ambient air in and about airports. These will allow formulating models relating vapor concentrations of explosives concealed in luggage, aircraft, lockers, etc., to concentrations which may be available for detection under practical operational conditions.

An extensive analysis of the vapors emitted from a broad range of explosives has shown up to 400 separately identifiable compounds. Many of these appear in extremely low concentrations and/or are prevalent in the normal airport environment. Of the many vapors measured, six classes have been selected as representative of all explosives of interest. Current activities are directed at establishing a vapor transport model for these vapors. The vapor transport model assesses the attenuation/time profile for the passage of the vapors from the explosive through normal baggage contents, the bag itself, and the ancillary vapor collection sytem. The result from this model is the concentration of vapor species available for detection and will be used as the requirements for the development of operational explosive vapor detectors. The scheduled completion date is November 1980.

Study to Determine the Validity of Biological Bomb Detection

VA Hospital Medical Research Wing, Philadelphia, PA.

Dr. G. B. Biederman has trained a number of gerbils (meriones unguiculatus) to detect a variety of explosive and other vapors at dilutions substantially greater than has been achieved with physical devices.[3] While this work represents a greater level of performance than had heretofore been reported, a number of operationally significant questions remained unanswered. Early in 1978, the FAA initiated a program with Dr. D. Moulton of the Veterans Administration to determine the sustained performance of gerbils and domestic rats in olfactory discrimination, the best training method to develop the animals for placement in an explosive detection system, and the effective repertoire of odors that these animals can be trained to detect. Among the questions to be answered by this study are:

- How do composition variations of the same explosive manufactured in different batches or by different manufacturers effect performance?
- What are the effects of masking odors on animal performance?
- What is the animal's effective working period?
- Does random variation of the concentration of sample vapors effect performance?
- What is the optimum conditioning for training animals.
- What is the temporal distribution of errors; false positive and false negative?
- What is the correlation of errors among multiple animals exposed to the same sample stream?

At the same time that the FAA is pursuing a scientific extension and validation by Dr. Biederman's work, other organizations will test systems supplied by Dr. Biederman in a working/operational environment.[4] The scheduled completion date of this program is September 1980.

Decompression Screening System

Transportation Systems Center, Cambridge, MA.

A problem associated with the use of vapor for measurement is acquiring the maximum available concentration of explosive vapor for measurement. In a nonautomated environment, the sampling probe is placed near seams and keyholes in a suitcase. In automated environments, one means for sampling has been to pass the luggage through an air curtain. The FAA has developed an automated technique for passing luggage into a sealed chamber, minimizing the enclosed volume and collecting a vapor sample from inside the luggage by evacuating the chamber. An experimental model, Figure 1, was delivered in early 1978 and has been tested using target vapor sources.

The test results indicate the vapor samples extracted from the bags were diluted to only 40 percent of the internal concentration while processing bags at a throughput rate of eight bags per minute.[5] This represents an improvement on the order of 10^3 in vapor concentration compared to air curtain sampling and is applicable to any type of vapor detector. Further testing must await availability of viable explosive vapor detectors.

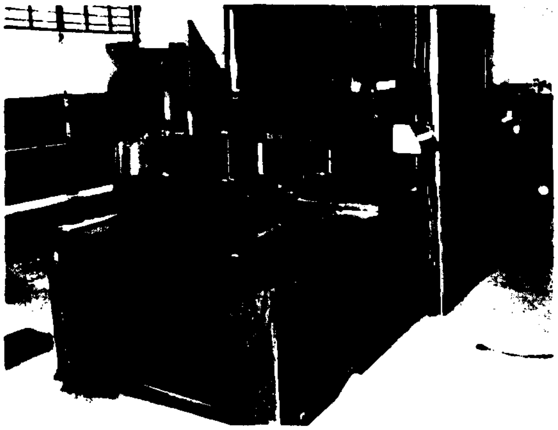

FIGURE 1.
EXPERIMENTAL DECOMPRESSION
SCREENING SYSTEM

BULK DETECTION SYSTEMS

The FAA is currently developing three different types of bulk detection systems. Nuclear Magnetic Resonance and Thermal Neutron Activation Systems based upon the chemical or atomic properties of the explosives, and an X-ray Absorption system based upon the physical size and X-ray characteristics of the explosives. The latter system is in essence a bomb detector rather than an explosive detector, although techniques may be available to overcome this deficiency.

Nuclear Magnetic Resonance (NMR)

Southwest Research Insitute, San Antonio, TX.

Following a feasibility study in 1975, the FAA funded the development of an operational prototype explosive detector based upon the hydrogen NMR response of explosives.[6] Figure 2 shows a block diagram of the feasibility model NMR system. The feasibility study demonstrated the capability to detect quantities of less than one pound of explosive in a sample volume of 14 in. x 23 in. x 15 in. Means to discriminate against the response from nonexplosive items were developed and incorporated into the apparatus.

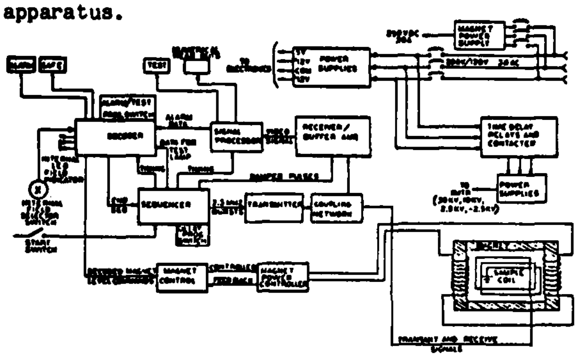

FIGURE 2
BLOCK DIAGRAM OF NMR LUGGAGE
INSPECTION SYSTEM

Tests of nonexplosive items showed no damage to an electronic watch, tape recorder, and a transistor radio. Prerecorded magnetic tapes were partially erased but were reusable without obvious adverse effects. The data content of magnetic stripping on credit cards was not adversely effected. Mechanical watches ran faster than normal after exposure to fields in the apparatus but were restored to normal operation by demagnetization. Tests with electrical blasting caps connected in normal firing circuits did not result in any detonations. Tests with and without simulated explosives gave correct indications greater than 83 percent of the time. The errors were associated with inhomogeneities in the polarizing magnetic field, a problem being addressed in the current development program.

In April 1979, the experimental NMR system was tested at Dallas/Ft. Worth Airport. More than 3,000 passenger bags were passed through the system. Data was taken for normal bags with and without the addition of explosive simulants. At the time of this writing, while generally most encouraging, the test results uncovered several equipmental problems. Minor modifications to the system are being made prior to reevaluation in 1980.

Thermal Neutron Activation

Westinghouse Research Center, Pittsburgh, PA.

The thermal neutron activation explosive detector is based upon the thermal neutron reaction N^{14} (n, γ) N^{15} with nitrogen, an element common to all explosives. In this reaction, the N^{14} nucleus captures a thermal neutron to form excited N^{15} which promptly emits a 10.8 MEV gamma photon in approximately 15 percent of the reactions.

To avoid false alarms due to the presence of nonexplosive nitrogeneous materials such as wool, Orlon, silk, and leather, the detector system senses the density as well as the quantity of nitrogen. Nitrogen density is greater for explosives than normal baggage contents. Figure 3 shows a typical nitrogen density profile for a bundle of dynamite in a large suitcase. Background was suppressed by setting the threshold at 211.

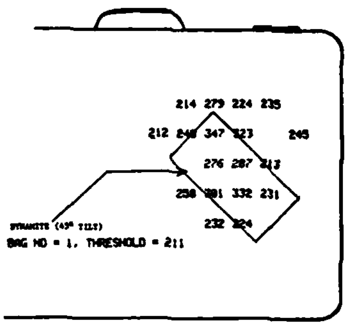

FIGURE 3
NITROGEN DENSITY PROFILE OF
DYNAMITE IN A LARGE SUITCASE

The results from a feasibility study showed that even with the low resolution imaging system employed in the experimental detector, bombs large enough to damage an aircraft could be easily detected and that there was no difficulty in discriminating against shoes and large numbers of Orlon sweaters.[7]

The current program will develop an operational prototype neutron activation explosive detector. The first phase is the fabrication of a transportable experimental system which will be used at several airports to acquire data on typical passenger luggage. The use of actual luggage cannot be overemphasized. Experience has shown that simulation of the broad variety of luggage and contents encountered in commerical aviation is impractical. Realistic system evaluations require the use of statistically significant quantities of "real world" luggage.

The experimental system started airport test and evaluation in January 1980. Checked baggage evaluation will be completed by September 1980.

X-ray Absorption

Westinghouse Research Center, Pittsburgh, PA.

The X-ray absorption bomb screening system for checked baggage is the first system to have successfully passed airport operational testing.[8]

In operation, a relatively low resolution (2 cm x 2 cm) digitized X-ray transmission image is computer processed to automatically sound an alarm when the programmed criteria for one of several typical bomb configurations are encountered. In operation, a ^{133}Ba radioisotope is collimated into a fan beam which illuminates a vertical line of 48 NaI (Tl)/photo-multiplier scintillation detectors. The bag is carried past the line of detectors on a moving belt. Under computer control, the analog outputs from the detectors are scanned, digitized and passed to a LSI-11 mini-computer for processing. Figure 4 shows the basic structure with covers and luggage belt removed. On the right side are the 48 photo-multiplier tube detector assemblies in the lead collimating shield. On the left is the container for the ^{133}Ba source together with the collimating slit which defines the fan beam of radiation.

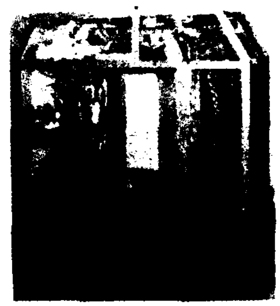

FIGURE 4
X-RAY ABSORPTION UNIT,
COVER AND BELTS REMOVED

Two different algorithms have been evaluated. The first, developed by the Westinghouse Research Center, identifies all pixels where a preselected absorption threshold is exceeded and applies a set of pixel connectivity rules to identify images characteristic of bombs. The criteria for bomb detection are based upon the analysis of data from more than 8,000 randomly selected bags at Newark International and Washington National Airports. Simulated bombs were added to approximately 25 percent of these bags.

Typical performance against this data is 85 percent detection with less than 15 percent false alarms while screening bags at the rate of one per second. Performance is quite sensitive to absorption threshold selection and may be varied to maximize detection or minimize false alarms.

A second processing algorithm being developed by the MITRE Corporation[9] using the same data base takes a more global view of the data. To date, using three features, contrast, Q (a measure of goodness to fit), and the minimum transmissivity over a scanning window, better than 97 percent detection was achieved at less than 5 percent false alarms. Figure 5 illustrates the results achieved for dynamite and C-4 based bombs using these criteria. The dashed curves are the results achieved with the simpler Westinghouse algorthim. Both are based upon the same data.

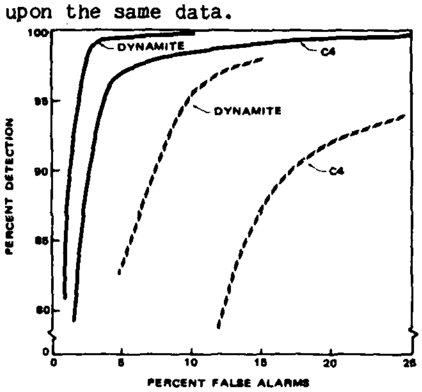

FIGURE 5
MITRE EXPERIMENTAL RESULTS

Table 1 summarizes the basis of the MITRE algorithm results. Here, too, the criteria can be adjusted to emphasize detection at the expense of increased false alarms. A major difference between the two algorithms is that the MITRE algorithm does not require preselecting a fixed absorption threshold, a quantity that appears to be sensitive to the airport location. It is anticipated that further performance improvements will be realized as new features are used in the pattern recognition algorithm.

Based upon the results of the experimental X-ray unit, the Westinghouse Corporation was awarded a contract for: 1) design improvements; and 2) delivery of two prototype automated X-ray checked baggage bomb screening units. Several design changes, including digital X-ray detectors, 2 cm x 1 cm collimating aperture, larger source and slower belt speed, all leading to improved signal to noise ratio, have been implemented. Prototype delivery and the intiation of laboratory testing began in Spring 1980. One unit will be installed at Dulles International Airport for 1 year of operational test and evaluation. The other will be used at NAFEC and at other airports for algorithm development and data acquisition.

TABLE 1 BASIS OF MITRE ALGORITHM RESULTS

DATA BASE - 1,344 SUITCASES

(747 CLEAN, 306 DYNAMITE, 291 C-4)

THREE FEATURES (2 WINDOWS)

- MINIMUM
- Q (A MEASURE OF GOODNESS TO MATCH)
- CONTRAST DIFFERENCE

TRAINING SET (20 CLEAN, 20 DYNAMITE, 20 C-4)

RESULTS (EQUAL THRESHOLD)

- 97.3% DETECTION
- 4.8% FALSE ALARMS

Dual Energy and Computerized Tomography (CT) Studies

New approaches which were explored in 1979 are dual energy X-rays and computerized tomography. Dual energy X-ray measurements permit measures of photoelectric and compton absorption coefficient, from which the atomic number and electron density of the materials being screened can be estimated. This has promise of extending the capability of X-ray based systems beyond the detection of size and density to material composition and enable direct detection of explosives as well as bomb-shaped packages. Computerized tomography, which can provide multiple-slice high resolution images, if coupled with dual energy measurements could potentially detect bombs/explosives in luggage even if they were in the form of pipe bombs or rolled out plastic explosives. Moreover, it should be able to do so even if shielding is attempted. Obviously, large amounts of shielding could "hide" a bomb, but that in itself would be detected and be the cause for alarm.

The results of a dual energy X-ray study performed by Varian Associates[10] indicate that the broad range of explosives measured could indeed be readily identified. It was found they could be categorized into four classes, two of which were readily distinguishable from "normal" luggage contents by their composition; the other two classes of explosives had X-ray characteristics similar to a limited group of items which could be encountered in luggage but could be distinguished from the benign items on a morphological basis. These results are being integrated into the new development activity, Modular Automated X-ray to be described later in the paper.

Deactivation Tagging

Detection and removal has been the classical approach to the bomb problem. More recently, consideration has been given to an alternative, automatic bomb deactivation or neutralization of the bomb during routine screening. From a system point of view, deactivation is attractive in that it may avoid a major system cost, the personnel required to respond to system alarms, real or false. Studies of typical candidate bomb detection system airport installations suggest that personnel costs account for approximately 90 percent of the cost.

Using the current state-of-the-art, deactivation could be accomplished by the addition of a special "tag" during manufacture of explosives. Technical and economic considerations of alternative means for implementing deactivation suggest tagging of blasting caps rather than bulk explosives. Blasting caps (or the equivalent) are required to initiate high explosives such as TNT, dynamite, C-4 etc., approximately 100 million blasting caps, 80 percent electrically fired, are used annually in the US. Two possible approaches to deactivation tagging are: 1) to interrupt the electrical circuit; or 2) to release a reagent which will chemically react with one or more of the explosive charges in the firing train (primer, booster, or base) and neutralize them. Figure 6 shows a typical electrical blasting cap (EBC).

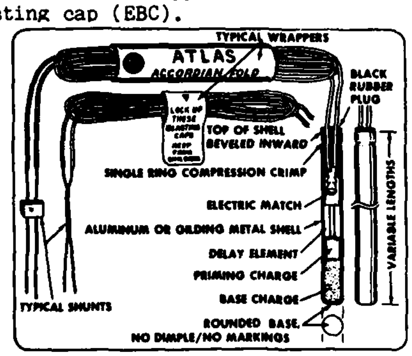

FIGURE 6
ATLAS ELECTRICAL BLASTING CAP

Magnetic Reed Switch Tag

One approach to electrical deactivation is to introduce a miniature switch/relay in series with the firing circuit. This switch would be normally closed until acted upon by an external screening field. Once opened, it should be impossible to reset. A miniature remanent reed switch meets many of the criteria for such a device except resistance to reset. When presented with this problem, R. M. Riley and his colleagues at the Bell Laboratories, Columbus, Ohio, came up with an innovative solution: the addition of a small amount of powered (nonconducting) ferrite to a remanent reed switch. Once the switch is opened, the ferrite is attracted into the high magnetic flux region between the contacts precluding resetting the relay. At the present time, there are no subminiature remanent reed switches (with or without ferrite powder) in production. One would have to be developed should this approach be pursued.

Frangible Capsule Tag

Conceptually, the incorporation of a reagent in a frangible capsule inside a blasting cap is extremely attractive. It could be used on both electrical and non-electrical blasting caps. The quantity of reagent required would most likely be quite small since typical quantities of explosives in the blasting cap range from approximately 0.2 grams for the priming charge and the booster charge to 0.4 grams for the base charge.

No reasonable approaches for implementing such a deactivation tag have been received. Some thoughts on the problem include:

For activation, use low frequency magnetic fields that can readily penetrate the conducting shell of the blasting cap.

Form the capsule from prestressed glass so that minor additional stress will result in rupture.

Include a "tell-tail". Some means of indicating that the cap has been deactivated is needed for blasting caps used in legal blasting operations.

The FAA is not currently planning to pursue deactivation tagging. The program has been transferred to the ATF, the Government agency primarily responsible for the control of explosives. Should deactivation tagging prove practical, the ATF would be the agency responsible for its implementation and control.

Future Activities

While each of the ongoing FAA R&D programs in bomb detection have high probabilities of successful performance in operational scenarios, they are far from panaceas. If used singly, each can be counteremeasured. If multiple disparate technologies are used in cascade, countermeasures become extremely difficult but costs and false alarm rates increase. The FAA is continuing its search for the most cost-effective solutions to aviation security.

A major new FAA initiative in the bomb detection area is the Modular Automated

X-ray Unit (MAX). The goal of this program is to combine the knowledge and expertise gained thus far in the experimental X-ray unit, the dual-energy study and pattern recognition development programs with state-of-the-art hardware components. The result is to be a high resolution, automated screening unit with dual-energy X-ray capability comprised of commercially available X-ray generation, baggage transport, data processing and display hardware which is operated by advanced, special purpose, transportable software. The initial unit will permit data acquisition in an airport or laboratory environment, algorithm development, and the evaluation of operational characteristics. By utilizing existing hardware, it affords the FAA the capability to rapidly implement automated screening of baggage whenever the need arises.

CONCLUSION

The FAA security system is adequate to meet the current threat. Research and development is continuing on more cost-effective security screening systems which will be capable of meeting new and more violent threats to aviation. Worldwide, there is a continuing increase in terrorism coupled with growing alliances and cooperation among international terrorist organizations. Achieving the necessary high level of security in civil aviation is costly, but necessary.

The FAA security program is geared to developing enhanced capabilities which can be quickly deployed when it becomes necessary to do so. While we believe we are addressing all known attractive approaches to solving this difficult problem, the door is always open to new approaches. Any suggestions will receive thorough consideration.

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FAA SRDS AIR TRANSPORT COCKPIT ALERTS/WARNINGS SYSTEMS

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BIOGRAPHY

John F. Hendrickson received his B.E.E. degree in 1956 from C.C.N.Y. and his M.S.E.E. degree from M.I.T. in 1959. He was a member of the MIT research staff at the Instrumentation Laboratory (now Draper Laboratories) and the Measurement Systems Laboratory where he was involved in the development of prototype inertial navigation systems, sensors and components. He subsequently joined the NASA Electronics Research Center where he participated in feasibility studies of strapdown inertial systems using redundant sensors and Laser gyroscopes. He came to the FAA SRDS in 1970, where he has been occupied, inter alia, with alert/warning system requirements since 1971. He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

ABSTRACT

Using the results of previous studies (1,2) in which current cockpit alerts and warnings were characterized, the Federal Aviation Administration (FAA) has initiated a developmental program which utilizes Government and industry resources to produce guidelines and criteria for a standardized alert system for air transport cockpits.

The previous studies produced two sets of conclusions as a result of the analysis of data collected relative to (1) the alerting situation in current air transport cockpit, and (2) human factors testing appropriate to alerting devices.

These conclusions represented a general set of recommended design guidelines:

o A consistent design philosophy that can be applied to all new aircraft irrespective of manufacturer.

o Relatively quiet, dark cockpit when all systems are operating normally and when abnormal situations have been cleaned up.

o Associate a unique, audio, visual or combination audio-visual method of alerting with each alert priority level.

o Provide alerting system growth capability in a form that does not necessitate additional discrete annunciators.

In addition to these general design guidelines, more specific human factors guidelines were developed.

The present phase of this program encompasses the development of candidate alerting system concepts, their implementation and evaluation in appropriate flight simulators.

a. BACKGROUND The FAA since 1970 has been examining the alerting systems in the air transport cockpit. The original purpose for this activity was to determine how a new alert for an independent altitude monitor could be introduced into the existing complement of alerts. The difficulties in developing a unique alert for this purpose led to the present program of reviewing the total alert/warning situation and developing a functionally standardized system.

b. TECHNICAL APPROACH Using the data collected during the previous studies, requirements for additional data have been defined. These additional data will fill in where gaps have been found in the existing human factors data.

The industry team composed of three major transport airframe manufacturers: Boeing, Lockheed, and McDonnell-Douglas, has reviewed the simulator facilities available to them and developed detailed and coordinated test plans. The FAA has approved the tests and schedules and the testing will be performed during the summer of 1979. The total set of data will be consolidated and analyzed to yield a definition for prototype alert systems concepts. After a review of the concepts, candidate systems will be selected using a criteria which will differentiate and establish the most viable systems for subsequent implementation for flight simulator testing. The next phase of the study will be the flight simulator testing to evaluate the candidate systems and to develop guidelines and criteria for the functionally standardized system.

Human Factors Testing

To augment the crew alerting systems data base, five categories of tests are being prepared for performance. By way of illustration, the following material describes one group of tests in detail, while only the problem statement will be presented for the others.

Test I - Crew Alerting Systems Data Base Augmentation - Visual Systems

Variable: Visual Temporal Format X Display Format X Pilot Workload

Problem: The effectiveness of any visual alerting systems is dependent on the detection and correct interpretation of the signals by the flight crew. Information is required to supplement the existing data base on the effect of certain system variables.

Test Objectives

I Augment the existing data base of information on visual caution and warning signal detection and identification.

II Provide data on the effect of a flashing master visual alert and workload on signal detection and the effect of message format on a central display on alert identification performance. The test should also provide an indication of the disruptive effectiveness of the master visual alerting format.

III Determine the impact of these findings on system design and standardization.

Output/Product

Comparative crew performance data on visual alerting signals, both master and programmable, which differ in format. Interaction of signal format and crew workload will also be reported. Recommendations on signal requirement and design specification will be made.

Data Measurements

The measurement will describe the time it takes a pilot to detect the visual alert and the central alert, the time to make a specified response to the signal, the accuracy of both the detection and response, the time to cancel the visual alert the sequence used in responding and a subjective evaluation of the aesthetic value of the signals.

Test Approach

This effort will develop empirical data describing caution and warning signal detection performance in a cockpit environment. The measurements will be taken in a simulated aircraft cockpit using two visual alert temporal formats (flash and no flash) and three central display formats (all alerts separate, warnings separate, no separation).

To simulate the aircraft environment, the pilots will be assigned flight related tasks (i.e., a short flight scenario) to accomplish. The workload imposed during the different phases of the scenario will have three general levels (high, medium, and low) and the alerts will be related to workload. All variables not included as test items will be controlled in the experimental procedures and design.

Performance measurements will be taken for all combinations of test variables. See Figure 1.

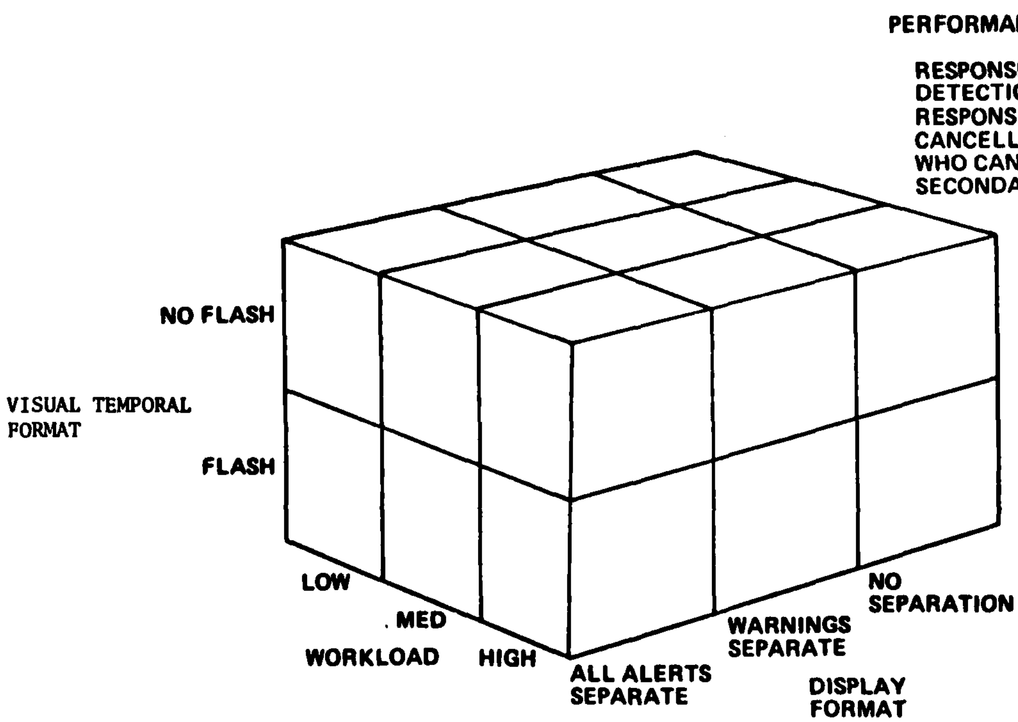

FIGURE 1. VISUAL ALERTS FORMAT VS WORKLOAD

Test II - Visual Systems

Variables: Visual Alert Format X Central Display Location X Central Display Cueing X Pilot Workload

Problem: The effectiveness of any visual alerting system is dependent on the detection and correct interpretation of the signals by the flight crew. Information is required to supplement the existing data base on the effect of certain system variables on detection and identification performance for visual signals and the design constraints produced by these variables.

Test III - Verbal Auditory Systems

Variables: Auditory Alert Format X Voice Model X Message Format X Signal to Noise Ratio

The effectiveness of any auditory alerting system is dependent on the detection and correct interpretation of the signals by the flight crew. Information is required to supplement the existing data base on the effects of certain system variables on detection and identification performance for auditory signals and the design constraints produced by these variables.

Test IV - Bimodal Systems

Variables: Alerting Mode X Cancellation Format Signal to Noise Ratio X Pilot Workload

Problem: The effectiveness of any crew alerting system is dependent on the detection and correct interpretation of the signals by the flight crew. Information is required to supplement the existing data base on the effects of certain system variables on detection and identification performance when both visual and auditory alerts are presented. What design constraints are produced by these variables?

Test V - General

Variables: Central Display Overflow Logic and Number of Non-Verbal Alerts

Problem: Some alternative system concepts and/or logic are difficult to test in an objective manner, however, information on these variables is required to supplement the existing data base and to determine design constraints which they produce.

Test Facility

In order to test and evaluate the prototype alert systems concepts developed in the course of this study, representative or simulated realistic environments are required. A facility with these characteristics is available and will be used for the comparative evaluation of the prototype systems. This facility is located at the Boeing plant in Renton, Washington, and with the capability for system changes and alternative mechanizations, it represents a flexible experimental simulation laboratory that allows easy introduction of new hardware and easy change to the flight deck configuration. Within the crew systems configuration are located standard aircraft instruments, a number of alphanumeric displays, a side arm control on the right side and wheel/column control on the left side, a throttle mechanism, clock display, two keyboard input devices, communication headsets, and cockpit speakers and microphones. These units may be directly wired to the Master Control Panel. This panel is located in the Master Control Console by which the test controller monitors and controls the test. The console interfaces with the stereo system, Cab Instrumentation Computer (PDP-11) and the projection system. The visual system provides out-the-window visual tasks for the test subject and is comprised of three independent projection systems.

Summary

The first phase of this activity has been completed. Complete cooperation has been experienced among the industry participants. The five human factors tests described in this report have been completed at the various facilities available. Tests I, II, and V were performed at the Boeing facilities and tests III and IV were completed at McDonnell-Douglas. Lockheed participated in the analysis of the results.

After completion and analysis of the test results, the government and industry groups will join together and define prototype alert systems from which selected candidates will be implemented for flight simulation testing. This testing will ultimately be used for the functional standardization of cockpit alerting systems. This study is an example of how, through the cooperation of the government and industry, results may be produced which will be useful to all parties concerned.

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HELICOPTER DEVELOPMENT PROGRAM

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BIOGRAPHY

Alvin F. Futrell received his Bachelor of Science degree in 1949, from the United States Military Academy. In 1976, he received a Masters degree in Transportation from Goddard College at Plainfield, Vermont. He joined the Department of Transportation (DOT) in 1967, and has been in Systems Research and Development Service (SRDS) since 1974. Mr. Futrell has over 20 years of active flying experience in both rotary wing and conventional aircraft. This experience included a three-year tour overseas as a helicopter unit commander, two years on the White House Staff, two assignments directing air taxi operations, and four years in a Federal Aviation Administration (FAA) Vertical/Short Takeoff and Landing (V/STOL) Office.

ABSTRACT

In September 1978, the FAA issued its initial Helicopter Operations Development Plan. The Helicopter Operations Development Program is a coordinated engineering and development effort directed by SRDS to develop improved capabilities in the National Airspace Systems (NAS) for helicopter operations. The objective of the helicopter development program is to improve all elements of NAS so as to enable helicopters to employ their unique capabilities efficiently. It includes an effort to generate sufficient expertise and data to support FAA regulatory activities in developing and updating criteria, standards, and procedures for safe and efficient operation of helicopters within the NAS. This paper presents the current status of the program.

BACKGROUND

With the first successful flight of the helicopter by Igor Sikorsky in 1939 and the first commercial helicopter certification of the Bell Model 47 in 1946, came the advent of an aircraft with the unique capability of hovering motionless over the ground and maneuvering in all directions free from the classic fear of stalling or from the need of a runway. Like all new concepts, however, much development was required to exploit its unique capability and commercial value. Payload, performance, and reliability were low, and maintenance and other operating costs were high. The helicopter's flight characteristics restricted it to the visual environment, and passenger acceptance was limited due to high vibration and noise characteristics.

All these factors militated against the helicopter's attractiveness as a commercial air vehicle except for those applications demanding the helicopter's versatility in vertical flight. Thus, the genesis of the commercial helicopter was somewhat bleak.

In the early 1940's, the military services adopted the helicopter where its practical value and potential was demonstrated. Development continued through the Korean War where helicopters were used in significant numbers for medical evacuation. Fifty thousand wounded soldiers were evacuated in that war, dramatic proof of the helicopter's practicality. That vivid demonstration has been repeated, not only in Viet Nam, but also during countless civil emergencies all over the world.

Today, the characteristics of the helicopter have improved markedly over the early helicopters of the 1940's and the 1950's. During the past 20 years, payloads have increased fourfold, and the payload-to-gross weight ratio has gone from one-third to one-half. Maximum speeds have increased from 120 miles per hour (mph) to over 200 mph, with similar improvement in cruise speed. Maintenance man-hours per flight hours, a major consideration in the cost of commercial operation, have decreased from 25 to 3, and overhaul intervals have gone from 600 hours in many cases. The total cost of ownership and operation has decreased dramatically from 47 cents per seat mile to 14 cents. Control system and electronic technology developments have yielded a helicopter sufficiently stable to be flown in the instrument environment. Requests for Instrument Flight Rules (IFR) certification and operation are increasing. All of these trends attest to the enhanced viability of the helicopter.

Today, we have over 7,000 civil helicopters in the U.S. fleet. Of this number, over 55% are currently engaged in commercial operation, about

30% in business/corporate activities and 15% in government-type work.

In the last few years, the helicopter fleet has been growing at an annual rate in excess of 12%. Thus, we can conservatively forecast that by the mid 1980's, we will have around 10,000 helicopters in the fleet of which we except a considerable number will have IFR capability. Helicopters are flying in support of oil drilling operations in the Gulf of Mexico, Alaska, and off the U.S. east coast, as well as in support of logging operations, executive transportation, traffic survey, and emergency medical and disaster relief. As the number and capability of helicopters increases, there is a commensurate need to generate data upon which to promulgate and update standards, regulations, and criteria pertaining to their certification and operation in the nation's air traffic system.

Major areas of emphasis in the FAA program include: IFR capability; icing; noise, crashworthiness, handling qualities; and finally, evolution of the Air Traffic Control (ATC) system and provision for greater operational capability in high density, offshore, and remote area operations. To carry out this activity, a helicopter program staff has been organized within the FAA SRDS to plan, coordinate, and manage the development activities in each of the functional areas needing improvement.

PROGRAM CONTENT

(1) CERTIFICATION: An initial report reviewing the airworthiness standards for certification of Helicopters for Instrument Flight regulation has been completed. It specifically reviews the Interim Criteria, Federal Aviation Regulations, Advisory Circulars and other pertinent FAA documents associated with the certification of helicopters for Instrument Flight. Identification of specific airworthiness requirements for helicopters operating in instrument meteorological conditions was studied and special attention was given to aircrew manning configurations, pilot flight control workloads, helicopter trimmability, static stability, dynamic stability, handling qualities, analysis of time history data and documentation procedures, augmentation systems, autopilots and review of certain flight test techniques. These requirements, will be validated thru follow-on testing at the National Aeronautics and Space Administration (NASA) Ames Research Center and at Canada's National Aeronautical Establishment in Ottawa.

An analysis was made of the numerous helicopters recently certified for IFR flight in order to identify the various systems utilized including avionics systems, display systems and autopilots. Special emphasis was centered on the study of a most critical IFR Scenario involving marginal stability conditions due to aft c.g., and high climb rates, etc., during missed approaches for CATEGORY I and CATEGORY II-ILS type procedures in adverse Instruments Meteorological Conditions.

A follow-on corollary effort to consider standardized evaluation procedures and performance criteria is in the final report stages.

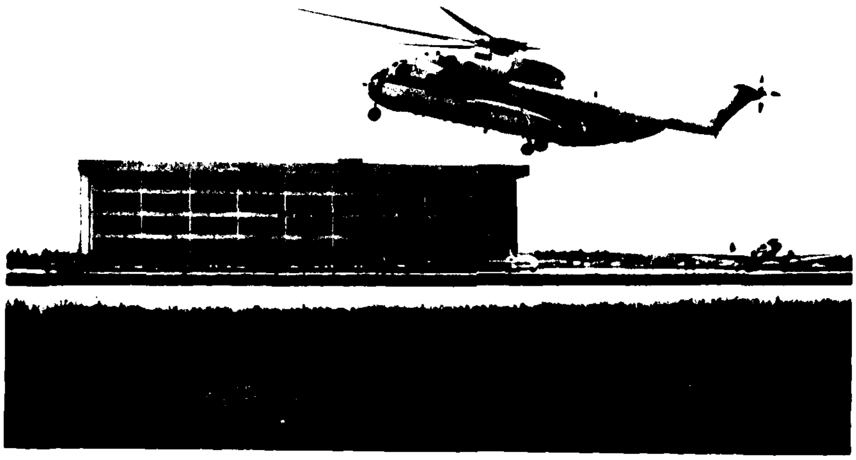
With the advent of signficant helicopter IFR flight, helicopter icing requirements are a major issue. To this end, a review of helicopter icing technology has been underway since December 1978 to define helicopter sensitivity to icing and to review operational icing experience. The FAA also participated in the Army '78-79 icing trials to study the effects of ice accumulation on unprotected rotors and fuselage. Simulated and actual icing tests were performed and the data are now being analyzed.

The helicopter program staff coordinated with NASA personnel in organizing a conference on icing held at the NASA Lewis Research Center, July 19, 20, 21, 1978. Staff personnel participated in this meeting to discuss questions concerning the icing environment, the forecast of icing conditions, the effect of icing on helicopters and rules of operation under icing conditions.

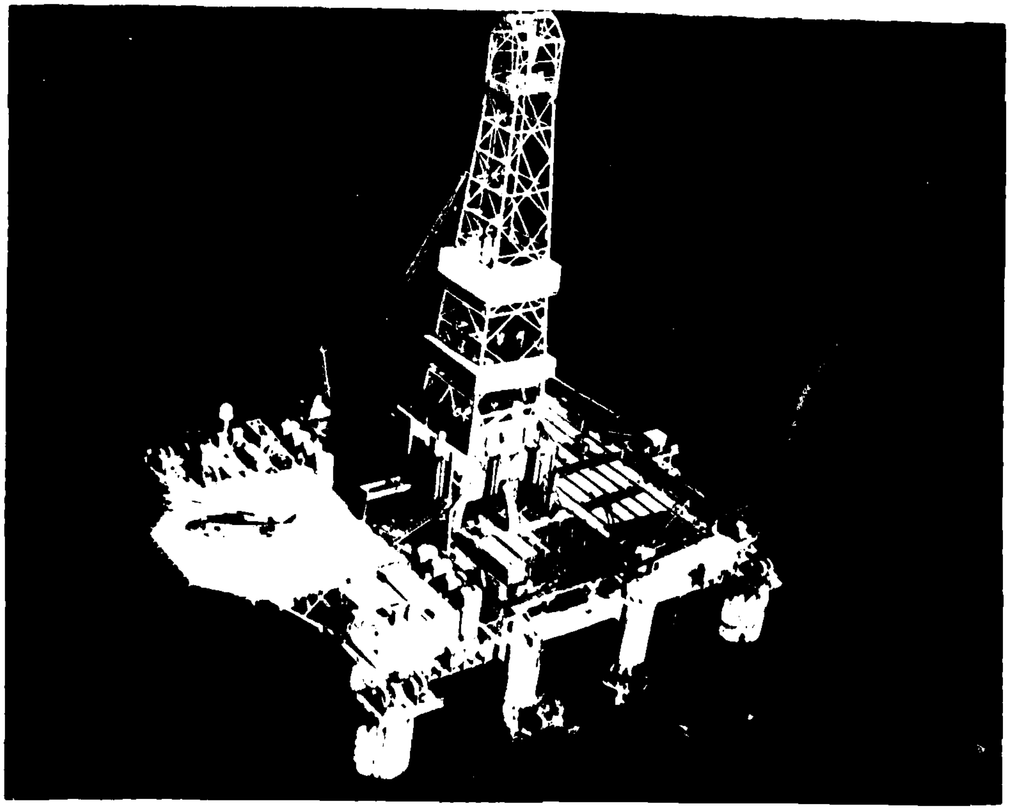
(2) ATC: Following the establishment of the helicopter R&D program and the development of the "Helicopter Operations Development Plan", FAA-RD-78-150, a specific effort was undertaken to scope in greater detail the ATC development portion of the program. This effort has been completed and a final report is currently being prepared. The report identifies offshore, intercity and remote area helicopter operational problems. It also identifies the available technology appropriate to solving the operational problems for helicopters. Finally, the report contains recommendations for short-term improvements to the ATC system and longer-term recommendations for simulating and testing more complex techniques for providing ATC services to helicopters in the future.

The results and recommendations of the R&D effort conducted to initially address the tasks of the Helicopter Operations Development Plan are contained in the, "Helicopter Air Traffic Control Operations", report FAA-RD-78-150, dated February 1979. This report concluded approximately 9 months of study and was the preliminary phase of the development program to improve ATC service for helicopters. The next phase of effort to be conducted will involve about a year and will implement the recommendations contained in the, "Helicopter Air Traffic Control Operations", report.

Initial contact has been made with most of the personnel actively concerned with helicopter air traffic control services. The offshore, intercity and remote area operators, as well as the FAA regional offices, ATC facilities, and district offices have been contacted and knowledge of their particular operational problems has been obtained. The Northeast Corridor (Washington to Boston) operators and manufacturers were encouraged to form a local organization (the Northeast Helicopter Council) to consolidate their needs and we have assisted



CH53 HELICOPTER



OFFSHORE PLATFORM

them and the Eastern Regional Office in arranging local meetings to address the problems of helicopter operators and the providers of ATC services. The operators currently using the Northeast Corridor (NEC) have reported improved ATC services resulting from this effort. The Eastern Region has informally approved helicopter departure routes from the New York heliports and airports and are in the process of obtaining formal agreements with all concerned. Visual Flight Rules route charts for the major airports along the corridor are currently being planned by a working group of the council. In order to establish a better understanding of the NEC among the FAA controllers along the corridor, we have taken steps to familiarize them with the pilot's route charts prepared by the Northeast Council.

In preparation for the anticipated IFR traffic growth in the NEC, we have completed formal arrangements to conduct a one-year extended test of the NEC, its associated spurs, and departure and approach procedures. The objectives of the extended test are to evaluate the NEC as it is currently designed, to modify and improve it as necessary, and to use the results of the NEC evaluation in establishing routes, and approach and departure procedures for helicopters in other parts of the country. Formal arrangements have been made to receive pilot reports from the users of the NEC and flight track records will be compiled to obtain a statistical measure of the suitability of the corridors' width.

We are also working very closely with the regional and facility representatives providing ATC services offshore. There have already been improvements to the offshore New Jersey operation, and we are currently assisting the Southwest Region in developing ATC services in the Gulf of Mexico. Routes and procedures are being defined which can be implemented within a year. In addition, a more comprehensive solution involving area navigation is being developed as a long-term solution.

A study has been initiated to evaluate new arrival and departure routes and approaches in the New York area, using the Microwave Landing System (MLS) to enable helicopters to make approaches on separate paths from fixed-wing traffic. These new routes and procedures will be examined initially by computer simulation.

Other advanced concepts will be examined for other parts of the country and for offshore areas to define the equipment, software and procedures required to improved the movement of helicopter traffic in IFR conditions. Experimental concepts and systems which appear promising as a result of initial studies will be developed and tested by simulation at the National Aviation Facilities Experimental Center (NAFEC) and later by field test.

(3) COMMUNICATIONS: The ATC system is highly dependent upon good, reliable communications with the aircraft in the system, and the normal operation of helicopters create communication problems. They generally fly at low altitude and are frequently beyond the line of-sight which limits our standard Very High Frequency communications systems. To find a solution to this problem, we have begun a study of existing communications services and potential new systems that will reach low-flying helicopters. A quick solution for the operations off the New Jersey coast has already been implemented, and priority is being given to the definition of a communications system that will support ATC services in the Gulf of Mexico; however, our goal is to define a standard system suitable for low-flying helicopters throughout the NAS.

(4) NAVIGATION: The low altitude flight profile of helicopters also creates a problem in using our standard VHF VOR/DME navigation system. The offshore helicopter operators are currently using Omega with special approval, and they are seeking approval to use the more accurate Loran-C system. To support approval of these navigation systems, we have carried out a series of flight tests of Loran-C and Omega in helicopters. The systems have been checked on oil routes offshore for Massachusetts and New Jersey and in the Gulf of Mexico; and a special series of Loran-C tests were conducted jointly with the Coast Guard along the NEC helicopters routes from Boston to Washington. Information has been collected on the accuracy of these systems as well as potential problem areas that require precautions by operators and approving authorities.

(5) APPROACH AND LANDING: The approach and landing phase of flight is that phase where the helicopter has unique capabilities, and there may be a possibility to exploit these capabilities by revising FAA's rules and procedures. Approach to offshore oil rigs also present a special situation that may justify special criteria for helicopters. Our initial investigation into this subject involved a flight test evaluation of airborne radar as an approach aid for helicopters. These tests provided data for Flight Standards to use in developing an advisory circular for approval of airborne radar approaches and for Radio Technical Commission for Aeronautics to use in developing minimum operational performance standards for airborne radar.

We have also initiated a study of the present criteria for helicopter instrument approach procedures to identify possible changes that may be justified now and to identify the requirements for test and development efforts that will lead to future changes that would enable helicopters to employ their special capabilities.

MLS can provide special benefits for helicopters and we have started to examine those applications which will yield those benefits.

Flight tests are being conducted with a CH-53 helicopter, at NAFEC, to evaluate special helicopter approaches along the NEC. These tests will be conducted to determine the need for improvement in currently defined approaches which terminate at a point in space several miles from landing sites in Metropolitan areas. In addition, the suitability of Loran-C will be evaluated as a low-approach guidance system for use by helicopters.

(6) WEATHER: Concurrently with the development of criteria for approving helicopter operations in icing conditions, a joint program has been initiated between FAA and the Naval Research Lab to gather more data on atmospheric conditions at low altitudes when icing conditions prevail. This information is needed to improve icing forecasts for helicopter operations as well as to develop ice detectors and to better define this environment in which helicopters should be tested for certification.

IFR helicopter operators in the Gulf of Mexico will require an expansion of aviation weather information services in that area. To provide assistance to the Southwest Region, a study has been undertaken to define an area-wide weather information systems for the Gulf of Mexico. This effort will define appropriate locations for weather observations, forecast requirements, and communication requirements for weather information.

The development of Automatic Aviation Weather Observation System (AV-AWOS) and Automatic Low-Cost Weather Observation System (ALWOS) for airports is being adapted to heliports and offshore platforms. AV-AWOS makes all the required observations for a Category II airport and ALWOS will be installed at facilities having an instrument approach, but no weather reporting system.

(7) HELIPORTS: A heliport design guide was published as an advisory circular in 1977. That guide provides recommendations for the establishment of heliports, but there is no current standard for lighting and marking of a heliport for use in IFR operations. Further, since the design guide was published, new ideas have been generated for lighting and marking of heliports.

Lighting and landing problems vary from one heliport to another but some exist at nearly all of them. Due to its smaller size, the heliport is most often located in a sea of metropolitan lights or an abyss of darkness, making it difficult to be located by the pilot.

Safety assurance requires that we have better lighting of the landing areas, without glare to provide better depth perception, better low level perimeter lighting for outlining the landing area, suitable high intensity light for locating the heliport, possibly a Visual Approach System Indicator (VASI'S) to aid in glide path control, plus a remote radio control for turning the system on and off from the aircraft.

As an initial step toward developing new standards for IFR heliports, we are accomplishing a comprehensive review of currently used lighting and marking systems as well as all new developments since the design guide was published. From this review we intend to identify one recommended system that may be adopted or, if necessary, tested and refined for adoption as a standard.

(8) TEST VEHICLE: As the growth of helicopter operations continues in NAS and developments continue to improve the capability of helicopters to operate in instrument flight conditions, there will be a continuing need to test and evaluate the compatibility of FAA's rules, procedures, and criteria with improved helicopter systems. For these reasons, action is being taken to procure a modern IFR-certified helicopter suitable for engineering and development testing by the FAA.

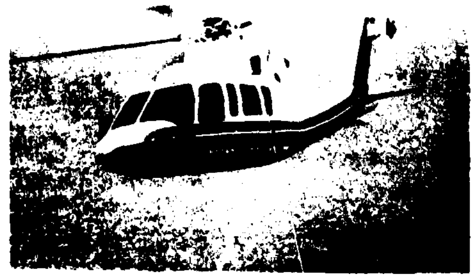
Many future test requirements can already be foreseen, e.g., new heliport lighting and marking concepts, MLS applications, new approach and departure procedures, new avionics equipment, noise abatement procedures, Global Positioning System, collision avoidance systems for helicopters.

A new helicopter is expected to be available in 1980 and it should be used to evaluate new ideas for helicopter operations and to familiarize FAA personnel with new helicopter capabilities.

SUMMARY

The FAA has recognized the need to update NAS to make it possible for helicopters to take advantage of their unique capabilities. An aggressive Helicopter Operations Development Plan has been prepared to accomplish this objective, it has been coordinated with the users and we are proceeding to implement an agreed program. The program involves work in every functional area of FAA's business; development of new certification and operational criteria, traffic control procedures, communications, navigation, approach and landing, heliport design, and weather reporting.

Each area of research agreed upon in our original Helicopter Operations Development Plan is being pursued aggressively and the results are already beginning to show in most of these areas.



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LORAN-C DEVELOPMENT PROGRAM

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BIOGRAPHY

George H. Quinn received his Bachelor of Science degree in Electrical Engineering in 1961 from the Pennsylvania State University. He joined the Systems Research and Development Service of the Federal Aviation Administration in November 1969 where he has been continuously involved in the development of long range navigation systems. From 1961 through November 1969, Mr. Quinn was employed at the FAA National Aviation Facilities Experimental Center (NAFEC) in Atlantic City as a project manager for the evaluation of long range navigation systems in aircraft.

ABSTRACT

This paper reviews the FAA Loran-C development program. Goals of the program are discussed along with the plans for meeting those goals. Selected technical approaches are discussed in some detail for each of the major areas involved with the incorporation of a new navigation system into the National Airspace System.

I. BACKGROUND

A. LORAN-C. Loran-C is a pulsed, hyperbolic system, operating in the 90-110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The usable coverage from a Loran-C chain is determined by rated power of the stations, atmospheric noise, geometric relationship of the stations, and the specific capabilities of the receiver. The effective ground wave range from individual stations is typically 600 to 1,400 NM over sea water and depends on station power and the capability of the receiver. Measurements are made of a zero crossing of a specified RF cycle within each pulse. Making this measurement early in the pulse assures that it is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To prevent sky waves from affecting measurements, the phase of the 100 kHz carrier of each pulse is changed in a predetermined pattern. The nominal coverage area is based upon the assumption that the receiver being used can acquire and track Loran-C signals when the signal to atmospheric noise ratio is at least 1:3.

The Loran-C propagation mode most frequently used for navigation is the ground wave. Sky wave navigation is feasible but with some loss in accuracy. Although it is designed for use, and normally operated in the hyperbolic mode, Loran-C can be used to obtain accurate fixes by determining the range to individual stations. This is accomplished by phase comparison of the station signals to a known time reference to determine propagation time, and therefore range from the stations. This is referred to as the range-range (rho-rho) mode. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. This method of using Loran-C requires that the user have a very precise and stable time reference. The high cost of equipment of this type limits the use of this mode.

The inherent accuracy of the system makes it a suitable candidate for aviation applications. While the 100 kHz signal is affected to some extent by soil conductivity characteristics and terrain, it can be received in mountainous areas where VHF and UHF systems are unusable. However, some distortion of the hyperbolic grid has been noted. The long range nature of the Loran-C system makes it particularly desirable for application to remote areas where suitable sites for short range navigational systems may be limited. By 19[illegible] Loran-C signal coverage will include the U.S. Coastal area and much of the 48 contiguous states, part of Alaska, and the Hawaii area. An area in central U.S. will not be covered.

B. PROGRAM GOALS The primary goal of the Loran-C program is to determine whether it can replace the VOR-DME system in the post-1995 period. A secondary, but more immediate, goal is to determine the suitability of Loran-C as a supplement to VOR-DME. The program goals were formalized in the Department of Transportation National Plan for Navigation published in November 1977. A Federal Radio Navigation Plan has been recently prepared and it restates the intent of the government to consider Loran-C as a potential replacement for VOR-DME. The Federal Plan will be published in early 1980.

There are three general areas involved with the use of Loran-C:

(1) Loran-C Avionics:

A determination must be made that suitable avionics, in terms of minimum cost and performance, will be available to general aviation users of the National Airspace System (NAS). The production of low cost avionics must be possible, before the navigation system will be acceptable to the users.

(2) Loran-C System:

Assurance must be gained that the Loran-C signals in space, the physical arrangement of transmitters, and the system management are adequate to support navigation in the NAS.

(3) Impact on FAA:

Any effect on FAA operations and services caused by the use of a new navigation system in the NAS must be thoroughly examined, and preparations made to accommodate any changes.

C. SCHEDULE The schedule to be met by the planned Loran-C development program is bounded at the far end by the need for an FAA decision in 1982 on post-1995 system. The near term and intermediate schedule is limited by the ongoing projects that were initiated in the past two years, and by expected funding in fiscal years 1980 through 1982. The general program schedule is:

Present - March 1982

Examination of candidate systems for the post-1995 period.

April 1982 - May 1982

Comparison of characteristics and qualities of candidate systems.

June 1982 - July 1982

FAA decision formulation on the post-1995 air navigation system.

The longest item in the general program schedule is for the detailed examination of candidate systems. This can be expanded:

Present - September 1980

Plan needed studies, developments, and evaluations.

Present - July 1981

Procure studies, and develop equipment as necessary.

Present - July 1982

Conduct studies and equipment evaluations.

January 1980 - July 1982

Publish study and evaluation reports.

Of course, the above four schedule items do not occur in series since the several projects included, for the most part, are started and completed independently of each other. The objective of the schedule is to have all work completed by July 1982 to permit an FAA management decision by late 1982.

II. PROJECTS

Three of the ongoing and planned Loran-C projects will be discussed here to provide a more detailed view of a part of the FAA Program. An example project will be used for each of the three major areas discussed earlier.

A. LORAN-C AVIONICS The FAA will sponsor the development of a "General Aviation Loran-C Navigation Receiver." Use of data collected and analyzed in the development and evaluation of the receiver will assist in making the determination of whether Loran-C avionics can be produced that will meet the low-cost and minimum performance requirements of general aviation. The receiver is to be technically representative of expected low-cost Loran-C receivers of the foreseeable future. A three part approach to development will be followed:

(1) Design Study
(2) Laboratory Model Implementation
(3) Flight Test Model Development

Products of the Design Study phase will be a "Design Report" and a hardware/software "Specification" for a receiver. The design will include receiver performance criteria in quantitative values with an appropriate rationale for each value, or with a reference to a documented performance criterion (e.g., RTCA Minimum Performance Standards). General items to be addressed in the design will be: (1) signal reception, (2) signal processing and navigation, (3) receiver operation and displays, (4) data output for FAA evaluation purposes, and (5) mechanical considerations. Also to be included in the Design Report will be a series of trade analyses on technical and operational subjects. For example, a trade analysis will be required concerning the use of Loran-C hyperbolic time difference lines-of positions (LOP's), versus range-range circular COP's, versus a combination of hyperbolic and circular LOP's relative to signals being received.

Based on the Specification from the Design Study phase an operating model of the Loran-C receiver will be assembled for a laboratory demonstration of performance. The Laboratory Model will be a fully operational receiver with all electronic components and osftware the same as those to be used in the later Flight Test Models of the receiver. Dynamic operation of the Laboratory Model will be from simulated Loran-C signals and noise. A product of the Laboratory Model phase will be a Specification for use in the assembly of the Flight Models. The Flight Test Models will be built in accordance with accepted industry standards for avionics. Following assembly and initial demonstration of the Flight Test units, they will be delivered to the FAA for evaluations of performance. The final report from the FAA evaluation, along with information from the Design Study and Laboratory Model phases will constitute a part of the background for FAA decisions concerning the expected acceptability of general aviation Loran-C avionics.

B. LORAN-C SYSTEM Past work by the FAA and others has resulted in data that indicates potential problems in the use of Loran-C in aviation. Some of these problems relate to signal propagation and geometry. Signal propagation anomalies have been noted in mountainous areas; neither the cause of these anomalies nor the operational significance is fully known. The FAA program goal is to accurately measure any mountainous area signal anomalies, determine whether a solution is needed and, if needed, whether it is possible in both a technical and practical sense. To accomplish the signal measurement work, a van type truck has been procured and instrumented with a high quality Loran-C receiver (i.e., an Austron model 5000), a spectrum analyzer, and appropriate recording equipment. In preparation for use of the instrumented van, a contractor has studied the problem and prepared a detailed measurement and data analysis plan for use by FAA engineers. In accordance with the plan, it is intended to examine Loran-C signals at points near mountainous area airports in Vermont, New York, and Virginia. The time during which measurements will be made will include winter and summer periods in order to search for seasonal effects. Several fixed site Loran-C receivers will be used to supplement the data collected in the van. Another potential problem involving signal propagation could occur when aircraft in close proximity use signals from different Loran-C stations for navigation. The various combinations of propagation paths might result in significant differences in computer positions by the Loran-C receivers. The operational effects of such a situation and ways to prevent it will be examined. Results should be conclusive as to whether Loran-C signals will be suitable for aviation use.

C. IMPACT ON THE FAA The incorporation of a new navigation system into the NAS will inevitably have effects on FAA operations. The existing air traffic system was constructed around VOR-DME navigation. Pilots and air traffic controllers communicate in terms of VOR-DME quantities and station names. If Loran-C exists in parallel with VOR-DME, and in 1995 it replaces the older system, accommodations will have to be made throughout the NAS. Loran-C is an area navigation (RNAV) system by its nature with about 40 stations needed to provide signals over the continental United States, versus almost 1000 VOR and VOR-DME stations. Controller instructions to a pilot to fly a radial from a specific VOR may not be possible for the pilot operating with Loran-C unless the Loran-C avionics unit is designed to make equivalent computations. Route planning by the FAA could change because Loran-C signals are generally available from the ground up to any desired altitude used by civil aviation; VOR-DME suffers from line-of-sight restrictions that dictate the minimum usable altitude along routes. Also, VOR based routes increase in width at distances of more than 51 miles from the station because of the angular error characteristics of VOR; no such increase would be necessary with Loran-C. These are just a few examples of the potential impact on the FAA. To examine the problem in detail, studies will be conducted that will look into all facets of FAA operations (e.g., Flight Inspection, Notices-to-Airmen, charting, etc.) that might be affected by the use of Loran-C.

The three projects described are not the only Loran-C work planned by the FAA; they were examples. Following is a list of other efforts which are either in progress or planned;

(1) Evaluation of Loran-C as a Non-Precision Approach Aid in Vermont
(2) Evaluation of Loran-C as a Non-Precision Approach Aid in the Rocky Mountains.
(3) Evaluation of LOran-C Applications in Helicopters
(4) Development of a Loran-C Signal Monitor System to Provide an Advisory Service
(5) Development of a Loran-C Signal Simulator
(6) Development of Airborne Loran-C Antennas and Noise Reduction Methods
(7) Study and Measurement of Loran-C Interference

SUMMARY

The FAA Loran-C development program is in progress with the evaluation of existing equipment, and with available signal measurement devices. In fiscal years 1980 through 1982, the development of equipment will increase. By late 1982 enough information on the three major areas: (1) Loran-C Avionics, (2) Loran-C System, and (3) Impact on the FAA will be in hand for FAA management to make a well founded determination on the ranking of Loran-C as a candidate replacement for VOR-DME in the post 1995 period.

WIND SHEAR PROGRAM

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BIOGRAPHY

H. Guice Tinsley is Chief of the Wind Shear and WVAS Section (ARD-414). He has a BS in Mechanical Engineering from Purdue University and received a MS in Business Administration from The George Washington University in 1968. He has a Commercial Pilot rating and has flown a variety of military aircraft including a tour as a test pilot in the C-141 program at Edwards Air Force Base, California and F-4, Phantoms in Vietnam. Prior position with the FAA was Chief of the Terminal Navigation Branch with responsibility for CAT III ILS Development, All-Weather Landing Program and Airport Lighting.

FRANK G. COONS, Jr.
Acting Supervisory Meteorologist, Techniques
Development Section, Aviation Weather Branch, ARD-413

Mr. Coons was the associate program manager for ground systems and forecasting development in the FAA's Wind Shear Research and Development Program. He has been on the wind shear staff since its inception in August 1975. Prior to joining the Wind Shear Program, Mr. Coons worked for the FAA's Aviation Weather Systems Branch as project manager in fog dispersal systems evaluation and systems engineering studies of weather support for the Upgraded 3rd Generation Air Traffic Control System. Prior to joining the FAA in 1970, he worked as an Advanced Weather Officer in Headquarters Air Weather Service on a variety of weather related research and development projects. Mr. Coons has 3,800 hours of flying in weather reconnassiance aircraft. He graduated from Millersville State College, Pennsylvania in 1954 with a Bachelor of Science in Education. He received his basic meteorological training at the University of California at Los Angeles and his advanced training at Pennsylvania State University in 1964 and 1965.

LT COLONEL LARRY WOOD
Associate Program Manager for Airborne Systems

Colonel Wood is a member of the United States Air Force with an assignment to the FAA. He holds a BS and Masters Degree from the Air Force Institute of Technology in Electrical Engineering. He is a Command Pilot with experience in F-100's, B-52's, B-47's, and completed a Vietnam tour in O-1's. Colonel Wood was awarded the Distinguished Flying Cross and 18 Air Medals for his extremely hazardous flying activities as a Forward Air Controller. His present position in the FAA is the management of all airborne system developments relative to wind shear.

ABSTRACT

The Federal Aviation Administration's Wind Shear Program has developed three solutions to the aviation problems created by hazardous low-level wind shear. They include: development of a ground-based Low-Level Wind Shear Alert System to detect shear in the terminal area, development of a Hazardous Wind Shear Advisory Service in cooperation with the National Weather Service to alert pilots when strong wind shear conditions are going to affect airport operations, and development of avionic displays to assist pilots in coping with shear during approach and landing. Each of the above potential solutions is reviewed in this paper.

BACKGROUND - Wind Shear

Since July of 1973, there have been nine U.S. air carrier accidents attributed to encounters with strong low-level wind shear (as determined by the National Transportation Safety Board).[1] Within the past 36 months the efforts of the Federal Aviation Administration's (FAA's) Wind Shear Engineering and Development Program[2] have developed solutions to the low-level wind shear problem in three separate, but related, development areas. The purpose of this paper is to briefly review those solutions to the wind shear problem which could be fully implemented by 1981.

In constructing the FAA's Wind Shear Development Program, it was evident that no single area of investigation within the three major areas of the program plan would provide a total solution. Therefore, all three development areas have been pursued simultaneously. Those three major areas are: (1) develop a ground-based system capable of detecting strong wind shear conditions in major airport terminal areas, (2) provide a Hazardous Wind Shear Advisory Service for terminal operations based upon forecasts provided by the National Weather Service (NWS), and (3) provide an on-board indication of wind shear conditions to pilots for safe approach and landings.

The above solutions are currently being implemented.

GROUND-BASED WIND SHEAR DETECTION

In all the accident cases mentioned above, substantial differences existed between the surface winds reported for aircraft operations and the winds actually encountered by the accident aircraft. Normally, airport winds are measured in the runway complex as near as possible to the average aircraft liftoff position on the main runways. At larger airports this is often miles from the active approach zone being used at the time. For example, at Chicago's O'Hare Airport the centerfield anemometer, or operating wind sensor, is located approximately 2 nautical miles (3.7km) from the Instrument Landing System (ILS) middle marker of the approach to runway 14 left. When thunderstorms begin to impinge on the airport operating corridors, airport wind conditions can change dramatically over short distances and times. Winds measured at one point only, in most cases, will be much different than those encountered by aircraft operating in and out of the airport. This was dramatically illustrated by both the Eastern 66 accident at JFK which occurred on July 24, 1975, [3] and the Continental accident at Denver which occurred on August 7, 1975.[4]

Low-Level Wind Shear Alert System

A precursor of strong to severe low-level wind shear is a wind shift zone known as the thunderstorm gust front. The detection and movement of that zone is therefore important to safe airport operations. Over the past several years, the FAA has evaluated a number of ground-based wind shear sensor systems designed to detect hazardous wind shear in the terminal area. Of those designed to detect shear associated with thunderstorm outflows (and in particular the gust front), the Low-Level Wind Shear Alert System (LLWSAS) has been chosen for installation at 60 U.S. airports. The 60 airports were chosen on the basis of an FAA in-house benefit/cost study. The analysis weighed the cost of procuring, installing, and operating the LLWSAS over a 20-year period versus the cost of wind shear related air carrier accidents over the past 9 years and the potential of having another major accident due to low-level shear from thunderstorms. Sixty airports were judged to be cost beneficial for equipping with the LLWSAS.

The LLWSAS system consists of up to six additional anemometers nominally sited in the airport approach and departure corridors at from 3,000 (914km) to 4,000 (1.2km) feet from the runway thresholds. The wind sensors were mounted on wooden poles at altitudes that range from 20 (6km) to 50 (15km) feet depending upon the surrounding terrain and wind flow obstructions. At airports where the runway layouts do not lend themselves to 360 degree coverage, the sensors are located as before but also in the quadrants from which the maximum number of thunderstorms cross the airport.

Data are taken at each remote anemometer site and VHF* (169.375 MHz**) radio linked back to a receiver located on the airfield control tower where they are compared with the centerfield or operating winds. A mini computer, installed in the control tower equipment room, performs the system computations, command functions and drives system displays available to air traffic controllers. When the vector difference between any one or more remote sensors and the centerfield sensor exceeds 15 knots (7.7 mps), the controller's displays provide readings from the affected site(s) in addition to the centerfield winds. The 15 knot vector difference was selected as the wind shear alarm trigger point based upon a suggestion from Dr. Edwin Kessler, Director of the National Severe Storms Laboratory and Dr. Gordon Little, Director of Wave Propagation Laboratory of the National Oceanic and Atmospheric Administration (NOAA). Because of the extensive study and analysis by those laboratories of numerous gust fronts, they believe the 15 knot vector difference to be the appropriate value. Those readings are relayed to pilots arriving or departing the airport through the air traffic control voice frequencies. The LLWSAS accurately and reliably measures the low-level horizontal shear. Providing the pilot with this information would eliminate departures into a known hazard such as the Denver accident or approaches into severe thunderstorm outflow areas such as the JFK and Philadelphia accidents.[5] A concept of the LLWSAS is provided in Figure 1.

Wind data at each remote site are sampled every 10 seconds by the radio link. Winds from the centerfield anemometer are continuously averaged over 2 minutes with any gust exceeding a 9-knot threshold within the past 10 seconds also being displayed. All anemometers currently used in the system are Belfort Instrument Vector Vanes. The

* VHF - Very High Frequency
**MHz - Megahertz

mini computer is a Digital Equipment Corporation PFP-1103.[6]

The LLWSAS is capable of driving up to ten displays but most control towers at the candidate airports will require only two. A typical tower cab display is depicted in Figure 1. A typical TRACON* display is shown in Figure 2. The TRACON display shows only centerfield wind data as sensed by the LLWSAS. The displays are readable in bright sunlight and consist of numeric, seven segment, incandescent digits configured in up to

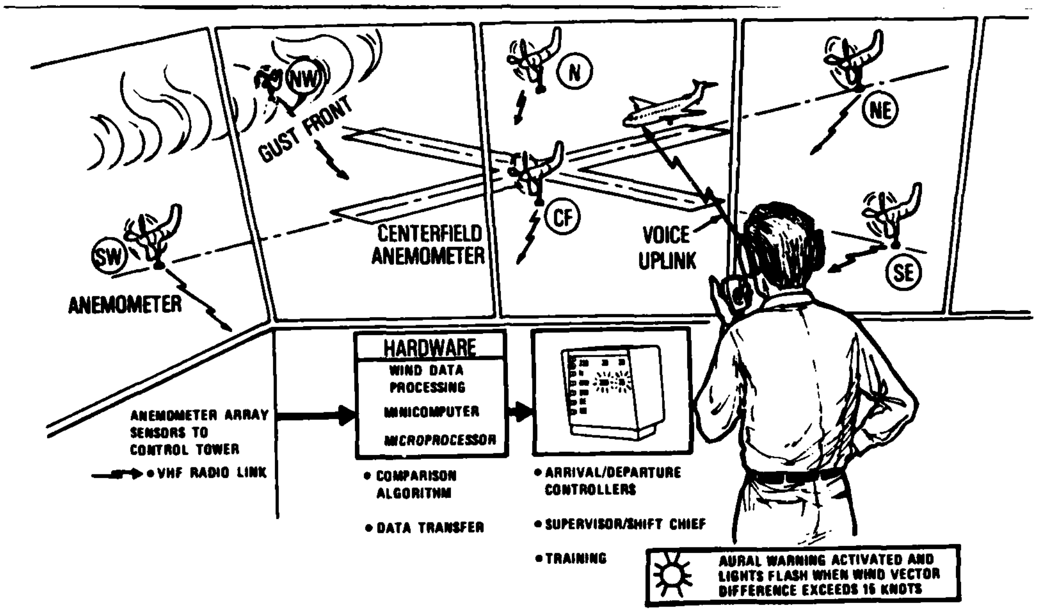

FIGURE 1. LOW-LEVEL WIND SHEAR ALERT SYSTEM CONFIGURATION

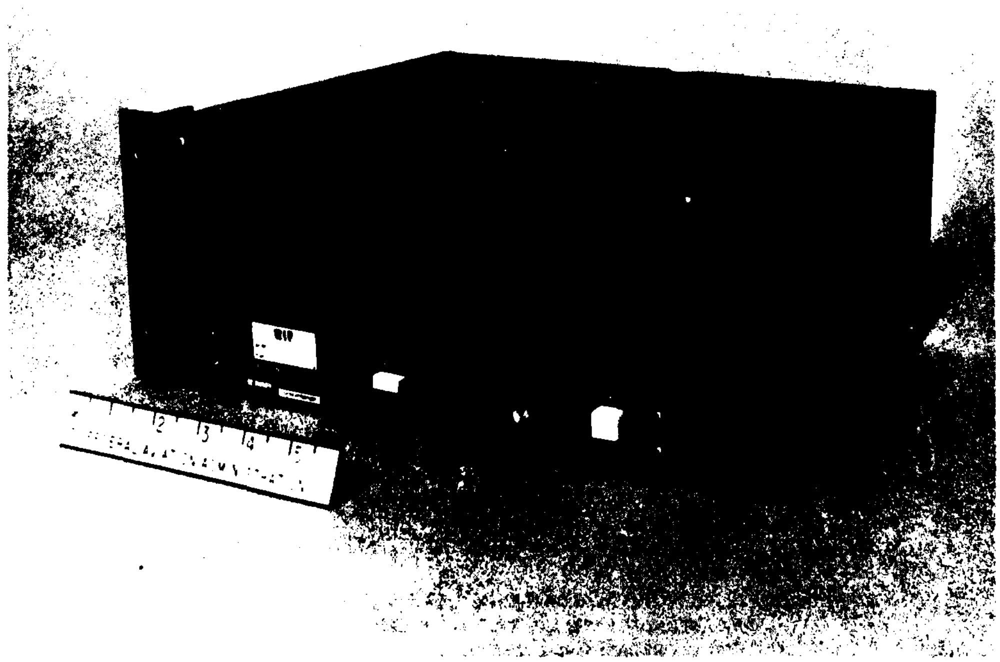

FIGURE 2. TRACON DISPLAY FOR LOW-LEVEL WIND SHEAR ALERT SYSTEM

* Terminal Radar Approach Control Facility

six rows. The top row of the tower cab display is always the centerfield wind direction, speed, and gust reading. Rows below the top relate to remote anemometer locations by general direction; i.e., north (N), northwest (NW), etc. The light intensity for each display line is manually controllable as is an audio alarm. Figure 3 is a photograph of a LLWSAS sensor site at Tampa, Florida.

Evaluation of the system was conducted at Denver, Houston, Oklahoma, Atlanta, Tampa, John F. Kennedy, and Boston Logan Airports. The LLWSAS is scheduled to be installed at 17 more major airports by the fall of 1979.

In addition to the implementation of the LLWSAS at many of the nation's major airports, feasibility studies were conducted on the use of a pulsed carbon dioxide laser and a pulsed Doppler radar to scan airport approach and departure corridors for low-level wind shear.[7] The laser failed to meet the range required (15km) in low visibility environments (heavy rains associated with thunderstorms). The Doppler radar, however, was much more promising in identifying changes in wind speed and direction when elevated at a 3-degree angle at ranges out to 20km to simulate a glide slope. Tests with the Doppler radar will continue through 1979 at the FAA's National Aviation Facilities Experimental Center near Atlantic City, New Jersey, to determine various scanning strategies and software requirements for displaying wind shear data in terminal area air traffic control facilities.

WIND SHEAR FORECASTING

Early in the manned simulation program conducted in the DC-10 at Douglas Aircraft Company, wind shear advisories were passed to subject pilots. Advance notice of impending shears was determined to be valuable information for a pilot to use in his approach strategy. If shear could be fore-

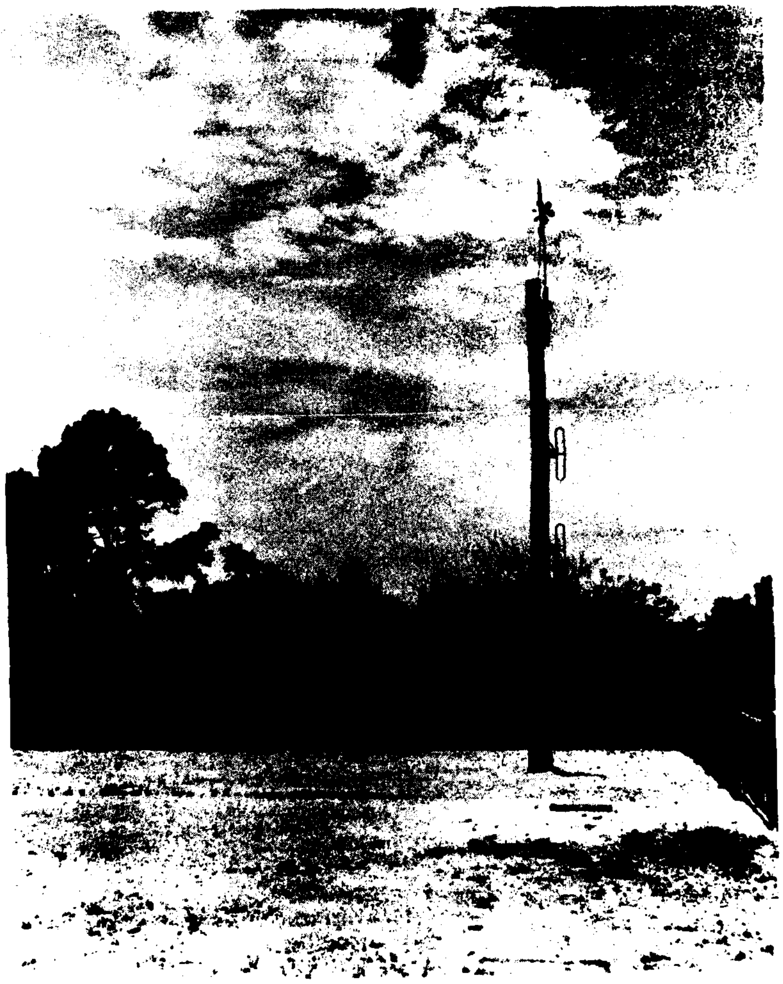

FIGURE 3. A TYPICAL LOW-LEVEL WIND SHEAR ALERT SYSTEM SENSOR SITE AT TAMPA INTERNATIONAL AIRPORT, FLORIDA

cast with a reasonable degree of skill, some benefit could be gained by passing this information to aircrews prior to landing or takeoff operations.

After a series of 1976-77 forecast tests sponsored by FAA in cooperation with NWS, several interagency meetings, two seasons of testing by the USAF's Air Weather Service, the forecasting of non-convective wind shear (shear not associated with thunderstorms) was implemented on a nationwide basis on April 16, 1979, by NWS meteorologists located in the Air Route Traffic Control Center Weather Service Units. Forecasts are made in less than 3-hour increments and appended to terminal forecasts in plain language abbreviated remarks. For example, Cold front 21Z 60 SCT 30 15G35 LOW LVL WIND SHEAR 23Z 80 SCT 30 15. Forecasts are generated through the use of a few simple rules and rely heavily on reports of shear by pilots operating in and out of the airports of concern.

Forecasts of shear associated with thunderstorm outflows (convective shear) is being pursued. with NWS on a long term basis. The developing of forecast skills in this area will be indeed tedious. Simple forecast rules to govern the speed, direction, and intensity of thunderstorm outflow zones do not presently exist.

AIRBORNE WIND SHEAR SYSTEMS

Nature of the Problem

The basic requirement of an airborne wind shear system is to detect the condition and inform the pilot of the severity. A decision can then be made to continue the approach or make a missed approach. If the approach is continued, the pilot requires guidance in the form of information displayed in the cockpit for controlling the aircraft through the shear condition.

Manned Flight Simulation

To aid in the selection of suitable wind shear related avionics, it was necessary to identify the various functions which an airborne wind shear detection/information system could fulfill and to evaluate the most promising approaches. A series of manned flight simulation experiments were conducted to identify and refine the most effective pilot-aiding concepts. The experiments were grouped into four phases of simulations using both training and engineering development simulators and modelling short-haul, medium-haul, and wide-body jet transport aircraft in current airline operations. The simulators were all equipped with six-degrees-of-freedom movement, visual systems with variable weather and visibility, and a full complement of controls for all flight crew positions. Each was capable of simulating all flight guidance and control modes available on the aircraft in service use.

Phase I of the simulation effort was a controlled screening of candidate systems and techniques.[9] The most effective were selected for in-depth analysis and further refinement. The bulk of these experiments were conducted in a DC-10 training simulator at the Douglas Aircraft Company Flight Crew Training Center in Long Beach, California. In this phase of the simulation effort, pilot performance data and subjective pilot opinions were recorded on highly experienced pilots, most of whom held DC-10 pilot qualifications. The pilots were subjected to various flight scenarios and wind shear conditions while being aided by several discrete concepts. Examples are:

(1) Wind Shear Advisories based on ground-based sensor data;

(2) Panel display of groundspeed versus vertical speed for a 3^{o} glide slope;

(3) Panel display of wind shear and direction (from INS*);

(4) Panel display of groundspeed integrated with conventional airspeed indicator (V);

(5) Panel and simulated head-up display of difference between along-track wind component at surface and aircraft altitude (W);

(6) Panel and simulated head-up display of flight path angle and potential flight path angle;

(7) Panel display of angle-of-attack; and

(8) Panel display of rate-of-airspeed change.

The results of those experiments indicated that groundspeed/airspeed comparison (V) ranked as the best aiding concept by pilot opinions and by the comparison of recorded landing performance.[10] The second best aiding concept was found to be the along-track wind component comparisons (W), either head-up or head-down, particularly when presented on a head-up display. There was also an indication that the head-up displayed flight path angle has some merit. As a continuation of Phase I, the top ranking aiding concepts were reexamined in the Flight Simulator for Advanced Aircraft (FSAA) at NASA/Ames Research Center using a Boeing 737 model. The results of that simulator experiment verified the findings from the previous Phase I simulation efforts.

Phase II simulation experiments were conducted in the Moving Base Development Flight Simulator (MBDFS) at the Douglas Aircraft Company facility using the DC-10 model.[11] These experiments provided an in-depth evaluation of improved V, W,

* INS - Inertial Navigation System

and flight path angle (both air and ground derived) displays. This activity also evaluated a modified flight director system (MFD) developed by Collins Radio.

The results of the more detailed evaluations in the Phase II simulations confirmed that the groundspeed/airspeed comparison (V) provides significant aid to the pilot and the along-track wind component comparison (W) provides some aid to the pilot in detecting and coping with wind shear. In addition, it was also shown that the modified control laws (algorithms) for flight director/thrust commands also significantly increased the pilots ability to handle wind shear encounters. Pilot acceptance of each of these concepts was high.

Phase III flight simulation experiments were conducted at both the NASA FSAA, using a Boeing 727 model, and at the Douglas MBDFS, using a DC-10 model.[12] The purpose of this series of experiments was to evaluate several different methods of displaying the V concept in the cockpit, to optimize the MFD control laws/algorithms for wind shear and to investigate the potential of two concepts to aid the pilot in making the missed approach or go-around decision. The go-around aids evaluated were:

(1) Panel display of energy rate (a comparison between actual total energy rate of change and desired rate of change for a 3° glide slope).

(2) Warning indication based on acceleration margin (a comparison between aircraft acceleration capability and the acceleration that will be required to overcome the shear (A)).

The Phase III simulation results again demonstrated that the V and MFD concepts were effective in providing the pilot the information required to successfully negotiate hazardous wind shear conditions. The V concept was successful in all the methods in which it was presented: groundspeed displayed on a digital readout; groundspeed displayed as a second needle on a conventional airspeed indicator (round dial); airspeed and groundspeed integrated into a special velocity indicator (vertical scale); or airspeed/groundspeed command displayed on the fast-slow indicator. In addition, it was shown that the A concept provided timely go-around information for those severe shears that approached or exceeded the performance capability of the aircraft.

The energy rate concept was shown to provide some aid to the pilot in making a go-around decision, but suffered from one serious drawback which is common to several of the unsuccessful concepts (such as angle-of-attack, airspeed rate of change, and flight path angle) which were tested in the earlier simulations. Although all of these concepts provide a positive indication of a shear condition and the severity thereof, the indication is not presented until the shear environment is encountered. In other words, the pilot is given an indication that he has entered a hazardous condition that he did not want to enter. On the other hand, those successful concepts which use groundspeed were shown to be predictive in nature in that they provide an indication to the pilot of the shear condition which lies ahead of the aircraft so that the pilot may take timely action.

Phase IV flight simulation experiments were conducted at the Douglas MBDFS, using a DC-10 model.[13] The purpose of these experiments was to validate the A, V, and MFD concepts under worse case conditions (high gross weight, high temperature, high altitude, low ceilings and low visibilities) and to evaluate the applicable concepts during non-precision approach and missed approach conditions. An existing airspeed indicator was modified to present an analog display of airspeed, groundspeed and the acceleration margin calculation all on the same instrument. This allowed the presentation of all wind shear information within the normal T-Scan of the pilot. The V, A, and MFD concepts were again proven to be successful, even under marginal performance and weather conditions, in aiding the pilot to safely traverse those shears which were within the performance capability of the aircraft and to detect and avoid those shears which approached or exceeded that capability.

Systems Descriptions

A brief description is in order for those systems which were demonstrated to be successful in aiding the pilot to detect and cope with hazardous wind shear.

Airspeed/Groundspeed Comparison (ΔV) -

The basic concept which has proven most successful in manned simulation experiments for a wide range of shear conditions on approach is the groundspeed/airspeed comparison. Basically, it is a simple procedure whereby the pilot computes a minimum desired groundspeed by subtracting the headwind component of the runway wind from the approach true airspeed. He then flys a normal approach using indicated airspeed, except that he does not allow the groundspeed to fall below the predetermined value. The procedure automatically causes the pilot to add additional airspeed to compensate for any airspeed loss that will occur when the shear condition is reached. It therefore acts as a predictive procedure so that if the amount of correction needed exceeds the known performance capability of the aircraft, the pilot is given the indication to perform a missed approach prior to penetrating the shear conditions (see Figures 4 and 5).

Modified Control Laws/Algorithms for Flight Director/Thrust Commands -

In addition to the above systems, modifications were developed for the control laws and algorithms which drive the flight director and thrust commands for control of the aircraft during

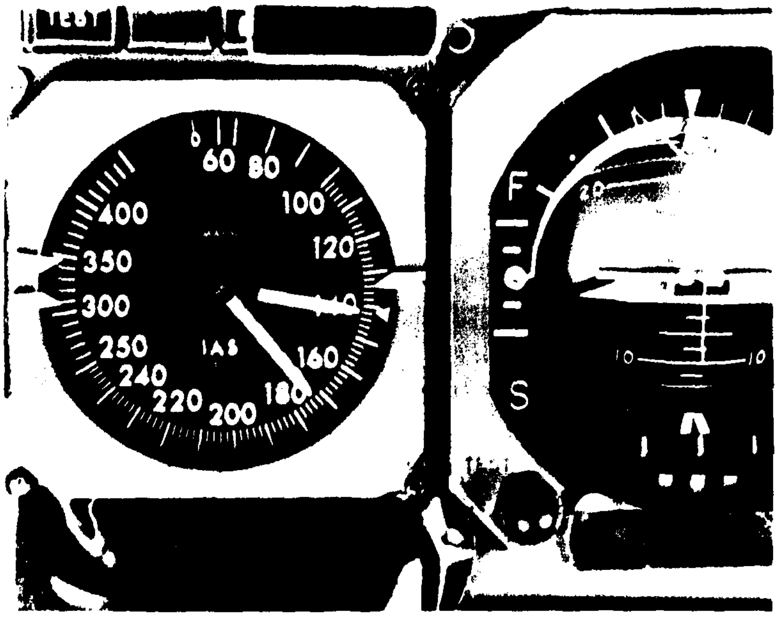

FIGURE 4. AIRSPEED/GROUNDSPEED COMPARISON

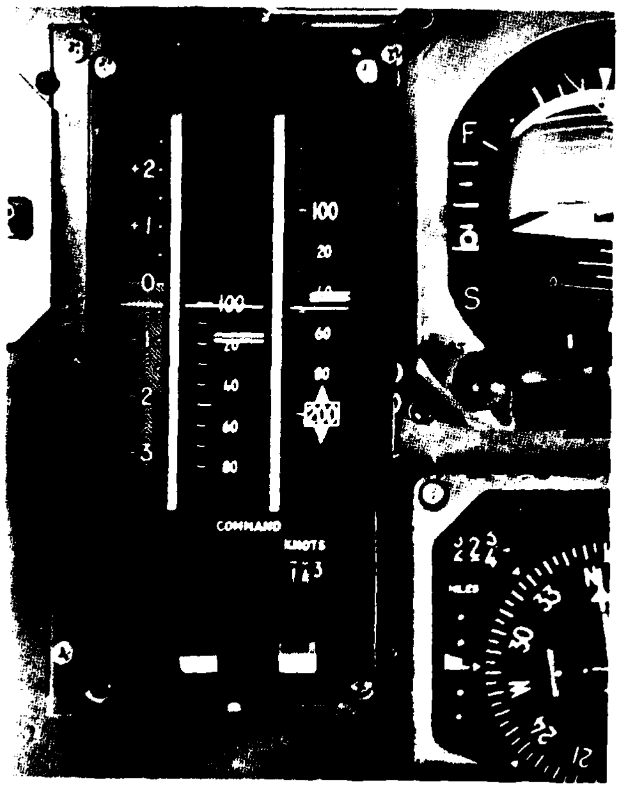

FIGURE 5. INTEGRATED AIRSPEED, GROUNDSPEED AND ACCELERATION MARGIN

approach. Modern systems are highly damped for passenger comfort and are not responsive enough for highly dynamic shear conditions. By providing the pilot with a selectable second set of control laws/algorithms which are quicker, more active, and based upon inputs derived from groundspeed, acceleration augmentation and tighter coupling to the desired flight path, the ability to traverse wind shear conditions is greatly increased (see Figure 6).

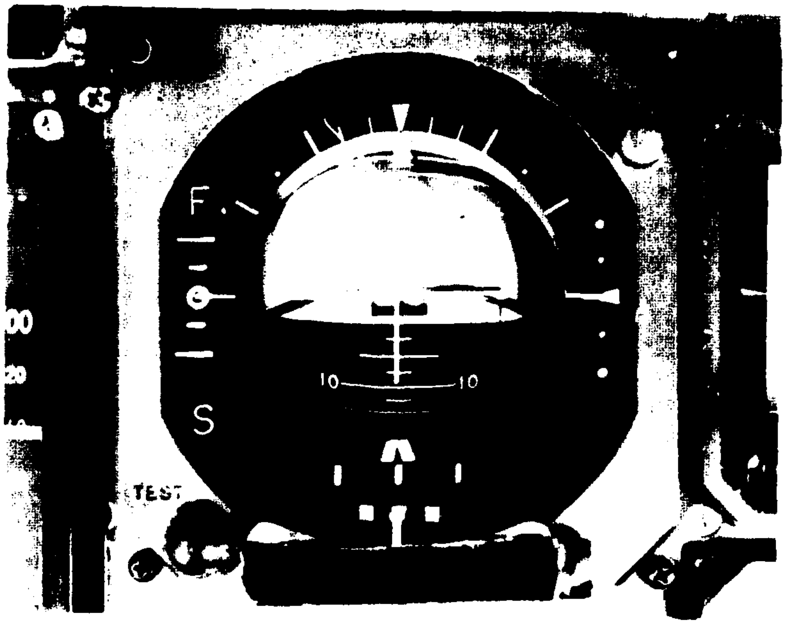

FIGURE 6. MODIFIED FLIGHT DIRECTOR (MFD) WITH QUICKER PITCH STEERING AND GROUNDSPEED/AIRSPEED AUGMENTED FAST/SLOW INDICATOR.

Acceleration Margin (ΔA) -

Acceleration margin is a measure of the difference between the acceleration capability of the aircraft and the acceleration that will be required to overcome the airspeed change which will occur if the shear is entered.

$$\Delta A = Aa - [Ws - (Va - Vg)] \frac{\dot{H}}{H} \text{ (Kts/Sec)*}$$

Where:

Aa - Acceleration capability of the aircraft computed from known performance data based on altitude, temperature, gross weight and approach configuration (Kts/Sec).

Ws - Headwind component of runway surface wind (Kts).

Va - True airspeed (Kts).

Vg - Groundspeed (Kts).

H - Altitude (Ft).

$\dot{H}$ - Altitude rate of change (Ft/Sec).

(See Figure 6)

Groundspeed Sensor Development

It should be noted that to implement any of the above successful systems, an accurate and timely groundspeed signal must be provided to the cockpit. Groundspeed bias errors must not exceed ± 2 knots with a 3 second update rate.[14]

Several methods for providing this information are being developed. The options are:

(1) Inertial Navigation Systems (INS). For those aircraft so equipped, groundspeed is readily available.

(2) Instrument Landing System (ILS). A groundspeed sensor which applies Doppler techniques to the RF* carrier or an audio subcarrier or an audio subcarrier of the ILS localizer.

(3) Distance Measuring Equipment (DME). Equipment/modifications designed to optimized the range rate output.

*Kts = Knots, Sec = Second, Ft = Feet

*RF = Radio Frequency

(4) Weather Radar. Groundspeed is determined by tracking a specially designed radar reflector on the ground.

(5) Radar Altimeter. A system which phase correlates the reflected radar altimeter signals received by two along-track antennas.

INS is already an operational system. The ILS, DME and radar altimeter systems exist in the prototype stage and are still awaiting flight testing. The weather radar system is under development. The fabrication and testing of several different types of equipment will allow development of the least costly methods for providing accurate and timely groundspeed to the cockpit.

Additional Airborne Systems Evaluation

Before any devised wind shear detection systems can be recommended for general applications to the aviation industry, their performance and characteristics must be validated in actual flight tests. Following tests in a simulated environment, both the groundspeed sensors and wind shear display systems will be installed in aircraft and adequately instrumented for flight tests. As airborne techniques and equipments are refined, flight tests will be conducted to determine specific performance requirements and capabilities that are necessary for airborne wind shear systems.

A Phase V series of manned flight simulation experiments is also planned. The purpose of this follow-on effort is as follows:

(1) Verify the results of Phase IV using a different simulator and a different aircraft model.

(2) Evaluate head-up display (HUD) as a wind shear aid under conditions similar to Phase IV.

(3) Determine methods of integrating the MFD, ΔV and ΔA concepts into HUD.

(4) Evaluate several commercially available wind shear equipments under conditions similar to Phase IV.

The combination of manned simulations, groundspeed sensor development and inflight testing will allow the selection, identification and description of those systems/procedures/equipments which can be used aboard an aircraft by the flight crew to detect and cope with wind shear. Such an all inclusive program should allow complete performance specifications to be written for the development of airborne equipment, permit detailed operational procedures to be recommended, and assure that the selected systems are cost effective. The information and data obtained in this program on airborne wind shear systems will be provided to the FAA Flight Standards Service, and ultimately to the aviation community at large, to support the rulemaking process. The FAA issued an Advanced Notice of Proposed Rulemaking (ANPRM) on May 3, 1979.[15] The notice addresses the requirement for airborne wind shear equipment in large passenger carrying aircraft.

SUMMARY

Three solutions to the wind shear problem have been reviewed. It appears that all three are required to reduce the hazard that low-level wind shear presents to safe air operations in the terminal area. The FAA will continue to pursue work in each area until the hazard is substantially reduced and essentially eliminated.

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EVALUATION OF HEAD-UP DISPLAY FOR CIVIL AVIATION

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BIOGRAPHY

William B. Davis, Jr. is a 1956 graduate of the University of Washington, Seattle, Washington, in Aeronautical Engineering. Prior to that, Mr. Davis spent 5 years as a carrier fighter/attack pilot in the U.S. Navy. After graduation, Mr. Davis joined the Northrop Aircraft Corporation as an aerodynamicist. In 1958, Mr. Davis re-entered the Navy where his duties included tours as a fighter and attack pilot aboard carriers, a flight instructor in the Naval Air Training command, and a radar air control officer aboard ship. In 1965, he joined the McDonnel Aircraft Corporation in St. Louis as a Senior Flight Test Engineer. In 1967, Mr. Davis graduated from the U.S. Air Force Aerospace Research Pilot School Experimental Test Pilot Course, at the Air Force Flight Test Center, Edwards AFB, California. Prior to joining the staff of the Federal Aviation Administration (FAA) Systems Research and Development Service (SRDS) in Washington, Mr. Davis spent 7 years as an Engineering Flight Test Pilot in the FAA Eastern Region. Since joining SRDS in 1974, Mr. Davis has worked in the FAA all weather landing program airborne systems as an evaluation pilot and project manager.

ABSTRACT

The performance of the Head-Up Display (HUD) and its effect on the conduct of all weather flight operations in the approach and landing phase are being examined in critical detail in laboratory, simulation and flight tests. The primary emphasis of this evaluation is safety related and concentrates on the contribution of HUD to flight safety in the operation of large turbojet aircraft. Other factors such as installation and maintenance costs, reliability requirements, and cost effectiveness will not be addressed.

The essential elements of HUD evaluation program consists of a literature search and background review, a series of related basic laboratory and simulation experiments, a full crew operational simulation evaluation and demonstration, and a flight test program consisting of an engineering evaluation and a flight demonstration program. Simulation and laboratory experiments are presently underway at the National Aeronautics and Space Administration (NASA) Ames Laboratory. Flight testing will be planned and conducted at the FAA National Aviation Facilities Experimental Center (NAFEC) during FY-80.

The literature search and background review (ref 2) recently completed, concluded that HUD has the potential of aiding the crew by reducing the cockpit workload, increasing instrument reliability, achieving redundancy of information for navigation, flight path control and other tasks, but that additional research is needed to define and document the advantages and disadvantages.

BACKGROUND

This project was initiated by letter from the FAA Flight Standards Service Director (AFS-1) dated April 20, 1976, requesting that FAA SRDS perform a research, development, and evaluation program of the HUD concept and to determine its contribution to safety in the operations of large turbojet transport airplanes during approach and landing. In a letter dated September 2, 1976, the FAA Administrator requested that NASA join FAA in the cooperative effort to investigate the safety potential of HUD. As a result, Task Order DOD-FA77WAI-725 to Inter-Agency Agreement NASA-NMI-1052.151 identifying the extend and the scope of the work to be performed was approved on March 9, 1977.

The primary objective of the HUD Evaluation Project is to determine the contribution, if any, of a HUD to aviation safety in the form of improved performance in the operations of large turbojet aircraft during approach and landing. To accomplish this objective, consideration will be given not only to the possible benefits that HUD may create in the operational environment.

This report updates the original HUD report of August 1978.

Summary of Part II: Laboratory and Simulator Tests.

1. Initial Piloted Simulation Tests

   a. Preliminary baseline tests of standard instrument approach procedures.

A study of transition to visual conditions from Instrument Meteorological Conditions (IMC). Test complete, report in writing.

b. HUD transition to visual condition from IMC

A manned simulation evaluation of the transition time required to assess visual cues at the decision height. Study is scheduled for late 1979.

c. Cross wind visual field requirements

A manned simulation evaluation in limiting cross wind conditions to determine minimum lateral field of view requirements and effectiveness of various methods of presenting symbology in the cross wind case. Study is scheduled for late 1979.

2. Perceptual Evaluation

a. Information Processing of HUD

A static test using airline pilot subjects to determine how pilots process information from two optically superimposed fields of HUD.

A NASA Ames research abstract published in October 1978 by NASA Ames. Final report in preparation at NASA Ames.

b. HUD Assessment Techniques Study Complete

"Viewing Duration of Instrument Panel and HUD Symbology Using a Recall Methodology," (ref 3).

"HUD Symbology and Panel Information Search Time," (ref 4).

c. Cognitive Switching Study

A static test using airline pilot subjects to evaluate the extraction of information from two superimposed sources of information.

Research abstract published in October 1978 by NASA Ames.

Final report in review at NASA Ames.

d. HUD Failure Annunciation Study

A literature search to evaluate existing HUD failure annunciation techniques with respect to eight evaluation criteria.

Final report in review at NASA Ames.

3. Symbology Evaluation

a. Assessment of Symbology Formats

An advanced flight path display evaluation two types of HUD concepts, conducted in a 6 degree of freedom manned simulator. Study complete. Report in preparation.

b. Assessment of flight director HUD versus situation display HUD

A manned simulation study completed in March 1979. Report in preparation.

c. Evaluation of HUD control law and symbology formats

A manned simulation evaluation of several symbology sets.

Evaluation is incomplete. Will resume in August 1979.

d. Peripheral Information Study

A manned simulation evaluation of peripheral information.

Tests completed. Part II is expected to be completed by the end of September 1979. A final report on the results of Part II should be completed by December 1979.

Report in preparation.

Part III: Full Crew Operational Simulation, using candidate HUD

This phase of the HUD evaluation will be conducted at NASA Ames in October and November 1979. The full six degree of freedom Flight Simulator for Advanced Aircraft (FSAA) with a REDIFON Visual system has been selected for this task. A candiate HUD selected from the evaluation of the Part II results will be used. This display will be computer generated.

Subject pilot selection will begin this fall and will include airline pilot crews as well as government and airframe manufacturer representatives.

Simulator Qualification of a Flight Quality Civil Aviation HUD

Using the results obtained from the preceeding joint FAA/NASA programs, the detailed requirements of a civil aviation HUD system will be developed. The system will be designed to have flexibility by being compatible with jet transports of the 1960's through those projected for use in the 1980's and will be capable of interfacing with current and future generation Air Traffic Control systems through the 1990's.

The flight quality HUD will be evaluated by FAA prior to flight test in a representative air carrier transport simulator. During this evaluation, the control laws and symbology selected from the earlier evaluations and software to position these symbols will be hardened. The final combination will be quantitatively and qualitatively evaluated using industry and user subject pilots. The simulation will also be used to further train those pilots selected for the flight demonstration program.

In addition, selected data will be gathered for use by the regulatory segment of FAA to assist in developing criteria and establishing a data base for determining certification requirements for HUD and other types of electronic displays.

Flight Test and Flight Demonstration

A flight test program will be conducted to validate the performance of all HUD subsystem and to correct any installation discrepancies. The HUD system performance will be evaluated against the onboard Inertial Navigation Systems during both precision and non-precision approaches at appropriate airports.

Flight demonstration tests will be conducted in an FAA B 727 using subject pilots who have been previously exposed to and trained in the use of a HUD system during one or more of the previously noted HUD simulation programs. The flight scenarios employed will be those developed and evaluated during the simulation HUD qualification tests. These scenarios will include Visual Meteorological Conditions and IMC precision and non-precision approach and landings in which HUD will be used as the primary and only instrument system.

Approximately 200 hours of testing will be subjectively evaluated to meet the Congressioanl briefing scheduled for March 1980. A more detailed quantitative and qualitative evaluation will be contained in a technical report scheduled for publication in September 1980.

Other potential uses of a HUD concept will be the subject of separate HUD programs. These include the use of HUD for other phases of flight, such as climb, cruise, descent, energy management and collision avoidance. Future applications such as display generation of curved and segmented flight paths will be evaluated in simulation as well as in flight.

SUMMARY AND FOERCAST

As each experiment is completed, an interim report will be prepared by the cognizant NASA experimenter. Several reports are now under preparation and have been sent to FAA for review. A final report on Part III data collection will start in January 1980 with completion, including final report, expected by June 1980.

A renewed interest in civil application of HUD recently appeared when several U.S. and International Airlines asked for HUD installations in their new generation aircraft. As a result, several airframe manufacturers have asked FAA for guidelines in the certification procedure for HUD.

To meet this requirement, FAA now has a more urgent need to obtain data and results from these NASA experiments. We have also recently completed an FAA-sponsored HUD simulation at Boeing in conjunction with the wind shear program. This program also familiarized FAA and airline pilots with the HUD concept.

Finally, to verify the results of the simulation program, FAA recently procured the HUD system for an agency Boeing 727 flight test vehicle at NAFEC.

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SYSTEMS INTEGRATION

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BIOGRAPHY

Roger G. Hunter is a electronics engineer of the Systems Integration Section, Systems Integration Branch of the Systems Development Division. He attended Ohio State University before joining the FAA in 1959. Since that time he has taught TACAN and the IBM 9020 computer at the FAA Academy; worked on the Minuteman Missile Program for the U.S. Air Force at Newark Ohio; designed equipment for helicopter overhaul for the U.S. Army at Corpus Christi, Texas; and designed intrusion detection equipment for the U.S. Army at Ft. Belvoir, Virginia. He first came to SRDS in 1970, and served for several years in the Spectrum Management Staff. He then worked with the DABS program and later served as DABS Section Chief. He then spent over a year at Los Angles ARTCC as a NAS Systems engineer before returning to SRDS in 1979.

INTRODUCTION

Integration of the R&D efforts of the Systems Research and Development Service, is an effort recognized to be required in order to assure an efficient and complete approach to product development. In the past, the responsibility for such integration of activities has been largely up to the appropriate program manager. Although it has produced a reasonable degree of success, nonetheless many problem areas w not surfaced sufficiently soon to be resolved before impacting other areas. A new approach is now being undertaken, with responsibility for identifying and coordinating systems integration problems now assigned to the Systems Integration Branch, ARD-440.

BACKGROUND

In 1972, the FAA published a document on the "Concepts, Design and Description for the Upgraded Third Generation ATC System." That document was in essence a description of how the FAA's Engineering and Development (E&D) community thought the future ATC system would evolve if the E&D programs underway or planned at that time were implemented. The document emphasized possible future operational capabilities rather than technical and operational interfaces since many of the planned improvements were still in the conceptual stage.

Some time later, the DOT conducted an extensive review of the FAA's E&D program aimed at providing products for the evolutionary improvement of the ATC system. The resultant DOT report recommended that the FAA's E&D program, then in progress be pursued but indicated that a description of how the various improvements would work together in the operational system was desirable.

Still later, the FAA's Office of Systems Engineering Management (OSEM) tasked The MITRE Corporation to develop a description of the ATC system as it might look in the future after the products of the E&D program were implemented. This was published as report FAA EM-78-16, "Definition, Description, and Interfaces of the FAA's Developmental Programs."

The purpose of the system description effort as defined by the Office of Systems Engineering Management was to:

- Describe the Conterminous U.S. Air Traffic Control (ATC) system after current major E&D features are developed and integrated into the operational system.
- Identify and describe the interfaces that would have to be provided between the system elements.

- o Identify and describe design and time phasing aspects of the program that required action on the part of the FAA.

The scope of this project was limited to those systems within Conterminous U.S. that are operated by the FAA and that are directly related to the provision of ATC services. In addition, the system improvements described were limited to those items in the current E&D program that were targeted for implementation, and that had been defined to a level of detail that their interfaces with other systems could be examined. Such efforts as the Automated Terminal System (ATS), the Automated En Route Air Traffic Control (AERA), and the use of cockpit displays, were considered to be at a preliminary stage of development and were not considered in detail, but their potential impact was briefly noted where applicable. Evolutionary system improvements planned for widespread implementation by the Air Traffic Service (AAT) and the Airway Facilities Service (AAF) were also included, but limited application system patches were excluded.

APPROACH

In developing the future ATC system description, steps were taken to first describe the various elements of the system and to then examine how the elements fit together as part of the overall system. More specifically, the first step was to identify the classes of facilities that would be examined individually. The facility breakdown used is shown in Table 1. The second step was to develop descriptions of each facility class based on current FAA plans and inputs from FAA personnel responsible for improving those subsystems. In the case of each facility class, a determination was made as to the functions to be performed, the inputs that were expected from other subsystems, and the outputs that were to be provided to other subsystems. Finally, the facility classes were examined collectively to ensure that there was a match between planned inputs and outputs. Cases where some additional examination may still be needed to assure compatibility were noted.

Facility descriptions were prepared for three time periods: Current, Near Term, and Far Term. The "Current System" was defined as consisting of those systems substantially in place by the end of calendar year 1978, including those system improvements that were funded for implementation in fiscal year 1977 or earlier years, but that were not completely operational by the end of calendar year of 1978.

The Current System was used as the reference point for examining system changes and is presented only to a level of detail that is necessary to highlight system changes.

The "Near Term System" was defined as the Current System modified to include those system improvements that could, according to current system plans, be substantially implemented by the end of calendar year 1982. Many of the anticipated Near Term improvements have already been approved for implementation and some have active procurement contracts. System improvements that have been approved for implementation have been noted in the documentation.

The "Far Term System" was defined as the Current System modified to include implementation of all system improvements in the current FAA E&D and operational service programs excluding non-CONUS, non-ATC, or long range research system improvements.

A summary of the various improvements that were assumed to be implemented in the Near Term Future ATC System Configurations is shown in Table 2. The table also identifies those improvements that have FAA and Department of Transportation approval for implementation. Most of the other Near Term and Far Term capabilities have been the subject of considerable development effort. Furthermore, it is the expectation of the FAA program managers that these capabilities would be implemented in the time frames indicated. A list of additional "potential" improvements is also included. These potential improvements include capabilities which are still in the conceptual stage or advanced development stage and have not yet been fully formulated to the point where they may be targeted for implementation in any of the time frames listed.

The Table 2 in this paper has been updated to show 1980 status.

Figures 1, 2, and 3 present an overview of the ATC system configuration in the Current time period, in the Near Term and in the Far Term, respectively. The ATC facilities in these figures, from top to bottom, are as follows: surveillance sites, tower cabs, TRACONS, ARTCCs, flight service facilities and system elements interfacing with them, and the ATC System Command Center. At the bottom of the charts are presented non-ATC facilities that interact significantly with the ATC system. The direction of flow of information from one facility to another is also indicated.

The block representing each one of the facilities has indicated in it the significant ATC system functions that are performed within the facility. The Near Term and Far Term improvements are also indicated within the facility blocks in Figures 2, and 3 respectively. The impact of these improvements on the functional flow of information is indicated in the figures in the appropriate time frame. A specific change from one time frame to another is highlighted by shaded areas and italics if the changes are within a facility. The impact of changes on the information flow is indicated by the use of italics. It should be noted that these figures are intended to highlight changes and improvements and they are not meant to be exhaustive in depicting capabilities, information flow, or connectivity. Thus, some systems features that do not change with the time were not included in the illustrations. Furthermore, Figure 1 presents only a brief listing of the capabilities of the Current system, since these capabilities are used only as a starting point for describing the future improvements. For example, the capabilities currently resident in the NAS Stage a system have been summarized by the following: Radar Data Processing (RDP), Tracking, Flight Data Processing (FDP), Input/Output and Display Processing, and Conflict Alert.

Finally, the number of each type of facility at the present time is shown in Figure 1. For example, there are currently 126 en route search radars. The numbers of facilities are not indicated in future periods because of the uncertainty associated with the deployment of various system elements.

The Figures 1 thru 3 in this paper have been updated to show 1980 status.

SYSTEMS INTEGRATION BRANCH

The Systems Integration function is new in SRDS, having been established in August, 1979. It was created in response to a recognized need for an organization with a broad view of SRDS programs, capable of identifying areas in the overall program wherein either voids or duplication of effort exist.

Additional functions of the organization include identifying and coordinating schedule and interface problems, coordinating hand-off of programs from OSEM to SRDS and from SRDS to the operating services, maintaining configuration control of all major technical systems, and management of reliability research for the service.

The approach taken by the Systems Integration Branch in attempting to identify and resolve program voids and overlaps, along with potential schedule and interface problems, consisted of starting with the MITRE report (FAA EM-78-16) as a baseline. A series of briefings, based on the report, in the areas of en route, surveillance, TRACON, Tower, Communications, Navigation, Flight Service Stations, and ATC Systems Command Center, were presented to the SRDS organizations involved in these areas. During the briefings, a number of the open items from the MITRE report were found to have been resolved. In addition, a number of new concerns were raised.

Following the series of briefings, an updated list of "integration issues" was prepared, reflecting current concerns. All concerns expressed at the briefings were recorded, even if they may have seemed trivial. An appropriate lead organization was then assigned to each item. With this new list in hand, meetings were held with individual divisions to cull down the list and identify the real issues. Some combining and some segregating of items resulted, culminating in a group of some 51 integration issues.

This final group of issues is still a dynamic document, but serves now to allow systems integration personnel to attack each issue individually and track the various interface and schedule problems to resolution.

The final group of issues is also being used as the basis for updating the original MITRE report.

SUMMARY

The Systems Integration function is still too new to access its value in improvment to the SRDS development process, however the cooperation and support provided to date indicates that the function is highly accepted within the service. As the work of the branch proceeds, it is expected that the divisions and program managers will increasingly utilize the services of systems integration.

TABLE 1
ATC SYSTEM FACILITIES

FACILITY CLASS	FACILITIES INCLUDED	PRIMARY OPERATIONAL SERVICES PROVIDED
En Route Facilities	ARTCC	En Route ATC control and flight data handling of IFR flights.
TRACON Facilities	ARTS IIIA, ARTS III, ARTS II, TPX-42	Terminal ATC control of IFR and VFR arrivals, departures, and overflights.
Tower Facilities	Tower cabs, electronic ground surveillance, wind shear and wake vortex monitoring systems	Airport ATC control of IFR and VFR landings, takeoffs, and ground traffic.
System Command Center	ATC System Command Center	Central IFR traffic flow management and central ATC emergency command center.
Flight Service Facilities	FSS, Automated FSS, Flight Service Data Processing System, Aviation Weather Processor	Preflight and weather briefing, VFR flight plan filing and monitoring, IFR flight plan filing, emergency location and search and rescue coordination services, weather and flight condition data acquisition and dissemination.
Surveillance Facilities	Search Radar, ATCRBS, DABS, Joint-Use Weather Radar	Electronic surveillance of airborne aircraft via primary and secondary radar and radar surveillance of weather.
Navigation Facilities	VOR/DME, TACAN, RNAV, ILS, MLS, NDB	Electronic guidance for en route, terminal and landing operations.
Communication	FAA voice and data input, output, switching, signaling, transmission, receiving and distribution facilities	Voice and data communication linking the facilities cited above -- ground-ground and ground-air-ground.

TABLE 2
SUMMARY OF ATC SYSTEM IMPROVEMENTS

FACILITY	NEAR TERM IMPROVEMENTS 1980-1982	FAR TERM IMPROVEMENTS POST-1982	OTHER POTENTIAL IMPROVEMENTS
ARTCC	• CONFLICT ALERT ENHANCEMENTS • EN ROUTE MSAW* • EN ROUTE METERING* • DIRECT ACCESS RADAR CHANNEL (DARC)* • CENTER WEATHER SERVICE UNIT (CWSU) • REMOTE MAINTENANCE MONITOR SYSTEM (RMMS) PROCESSOR • FSP REPLACEMENT	• ELECTRONIC TABULAR DISPLAY SUBSYSTEM (ETABS) • DIGITIZED DISPLAY OF WEATHER TURBULENCE • DABS/DATA LINK AVAILABLE • DABS/ATARS • CONFLICT RESOLUTION ADVISORY • AUTOMATED EN ROUTE ATC (AERA) • CONTROL MESSAGE AUTOMATION (CMA) • REPLACEMENT/AUGMENTATION OF EN ROUTE COMPUTERS (9020, CDC)	
TRACON (ARTS IIIA)	• SENSOR RECEIVER & PROCESSOR (SRAP)* • SEARCH RADAR TRACKING* • CONSOLIDATED CAB DISPLAY (CCD) • FDEP REPLACEMENT	• TERMINAL METERING & SPACING • TERMINAL INFORMATION PROCESSING SYSTEM (TIPS) • DISPLAY OF DIGITIZED SEARCH RADAR & BEACON TARGET REPORTS • DIGITIZED DISPLAY OF WEATHER (TURBULENCE) • DABS/DATA LINK AVAILABLE • DABS/ATARS • CMA • FULL DIGITAL ARTS DISPLAY (FDAD)	• ARTS III MAIN FRAME REPLACEMENT
TOWER	• VORTEX ADVISORY SYSTEM (VAS) • LOW LEVEL WIND SHEAR ALERT* SYSTEM (LLWSAS) • CONSOLIDATED CAB DISPLAY (CCD) • FDEP REPLACEMENT	• TIPS • ADVANCED VORTEX SYSTEM (AVS) • TOWER AUTOMATED GROUND SURVEILLANCE (TAGS) • AIRPORT SURFACE DETECTION EQUIPMENT (ASDE-3) • VISUAL CONFIRMATION (VICON) OF TAKEOFF CLEARANCE • TOWER CAB DIGITAL DISPLAY (TCDD)	• AUTOMATED TERMINAL SERVICES (ATS)
ATCSCC	• CENTRAL FLOW CONTROL ENHANCEMENTS (MORE REAL TIME DATA AND MORE ACCURATE SIMULATIONS)* • AUTOMATION OF CENTRAL ALTITUDE RESERVATION FUNCTION & AIRPORT RESERVATION OFFICE	• CENTRAL FLOW CONTROL ENHANCEMENTS	• CENTRALIZED FLIGHT PLANNING
FLIGHT SERVICE FACILITIES	FLIGHT SERVICE DATA PROCESSING SYSTEM (FSDPS)/AUTOMATED FLIGHT SERVICE STATION (AFSS) • AUTOMATED SUPPORT TO SPECIALIST: NOTAM & WEATHER INFORMATION MAINTENANCE & RETRIEVAL, AND FLIGHT PLAN FILING • ROUTE ORIENTED WEATHER RETRIEVAL • AUTOMATED ALERTS • DIGITIZED WEATHER RADAR AT 44 EFAS • SITES	FSDPS/AFSS • DIRECT USER ACCESS TERMINAL (DUAT) • VOICE RESPONSE SYSTEM (VRS) • SELECTIVE WEATHER RETRIEVAL • IMPROVED GRAPHICS (AFOS) • MULTIPLE WEATHER RADAR DISPLAY AT AFSS • AUTOMATED EMERGENCY MESSAGE GENERATION • AUTOMATED LOCATION INFORMATION AVIATION WEATHER PROCESSOR (AWP) • CENTRALIZED MAINTENANCE & DISTRIBUTION OF WEATHER & FLIGHT CONDITIONS DATA BASE	• GRID DATA BASE WEATHER SYSTEM • MORE CURRENT DATA ON UPPER AIR WIND/TEMPERATURE
SURVEILLANCE EN ROUTE	• DUAL COMMON DIGITIZER (CD-2)* • AIR ROUTE SURVEILLANCE RADAR (ARSR-3)*	• DABS/SURVEILLANCE, DATA LINK, ATARS • ARSR-4 • MOVING TARGET DETECTOR (MTD) • JOINT USE WEATHER RADAR (NEXRAD) • ARSR/RMMS	• ARSR WEATHER CHANNEL
TERMINAL		• DABS/SURVEILLANCE DATA LINK, ATARS • MOVING TARGET DETECTOR (MTD) • AIRPORT SURVEILLANCE RADAR (ASR-9) • JOINT USE WEATHER RADAR (NEXRAD)	• ASR WEATHER CHANNEL • LIMITED SURVEILLANCE RADAR
NAVIGATION	• SOLID STATE VORTAC*	• MICROWAVE LANDING SYSTEM (MLS) • VORTAC/RMMS	• SATELLITE NAVIGATION • TIME NAVIGATION
VOICE COMMUNICATIONS DATA COMMUNICATIONS	• SOLID STATE TRANSCEIVERS FOR ALL A/G/A COMMUNICATIONS* • NADIN* (CONSOLIDATE NASNET, AFTN AND SERVICE B. EXCEPT COMPUTER B INTO NADIN)	• VOICE SWITCHING CONTROL SYSTEM (VSCS) • RCAG/RMMS/MPS • NEW GENERATION VHF/UHF ANTENNAS • NADIN ENHANCEMENTS	• SATELLITE COMMUNICATIONS
AVIONICS		• BEACON COLLISION AVOIDANCE SYSTEM (BCAS) • DABS TRANSPONDERS • ATARS DISPLAY • DATA LINK DISPLAY • MLS	COCKPIT DISPLAY OF TRAFFIC INFORMATION (CDTI) HEAD UP DISPLAY (HUD)

*APPROVED BY THE FAA FOR IMPLEMENTATION

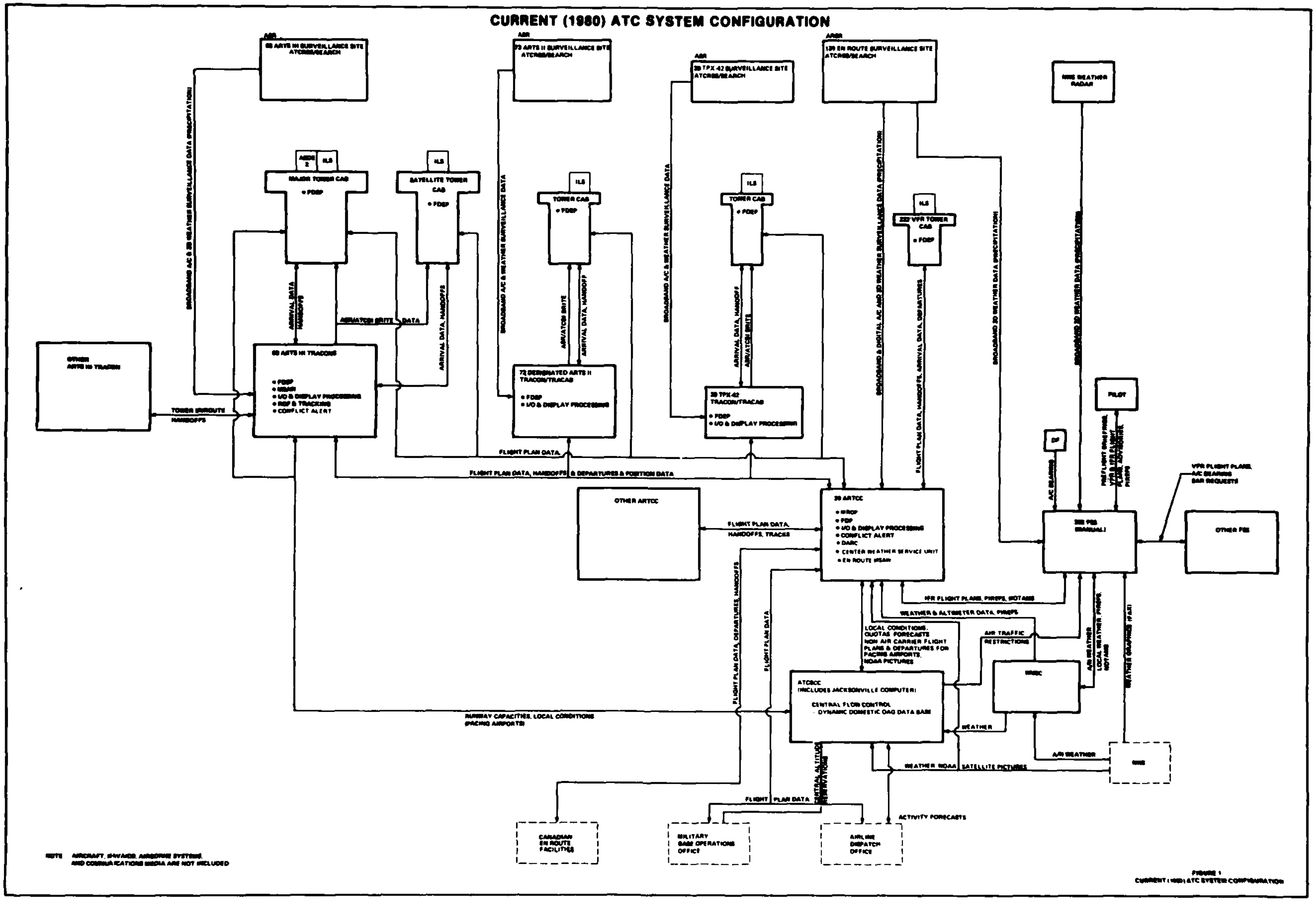
CURRENT (1980) ATC SYSTEM CONFIGURATION
ASR
ARSR
72 ARTS II SURVEILLANCE SITE ATCRBS/SEARCH
29 TPX-42 SURVEILLANCE SITE ATCRBS/SEARCH
129 EN ROUTE SURVEILLANCE SITE ATCRBS/SEARCH
ILS
MAJOR TOWER CAB
• FDEP
SATELLITE TOWER CAB
TOWER CAB
222 VFR TOWER CAB
OTHER ARTS III TRACON
TOWER ENROUTE HANDOFFS
• FDEP
• I/O & DISPLAY PROCESSING
• CONFLICT ALERT
72 DESIGNATED ARTS II TRACON/TRACAB
29 TPX-42 TRACON/TRACAB
ARRIVAL DATA, HANDOFF
ARRIVAL DATA, HANDOFFS
ARR/ATCRI BRITE
FLIGHT PLAN DATA
FLIGHT PLAN DATA, HANDOFFS & DEPARTURES & POSITION DATA
OTHER ARTCC
FLIGHT PLAN DATA, HANDOFFS, TRACKS
20 ARTCC
• FDP
• I/O & DISPLAY PROCESSING
• CONFLICT ALERT
• DARC
• CENTER WEATHER SERVICE UNIT
• EN ROUTE MSAW
PILOT
DF
A/C BEARING
OTHER FSS
VFR FLIGHT PLANS, A/C BEARING SAR REQUESTS
IFR FLIGHT PLANS, PIREPS, NOTAMS
WEATHER & ALTIMETER DATA, PIREPS
LOCAL CONDITIONS, QUOTAS, FORECASTS, NON AIR CARRIER FLIGHT PLANS & DEPARTURES FOR PACING AIRPORTS, NOAA PICTURES
AIR TRAFFIC RESTRICTIONS
A/R WEATHER
LOCAL WEATHER, PIREPS, NOTAMS
ATCSCC (INCLUDES JACKSONVILLE COMPUTER)
CENTRAL FLOW CONTROL
- DYNAMIC DOMESTIC OAG DATA BASE
RUNWAY CAPACITIES, LOCAL CONDITIONS (PACING AIRPORTS)
FLIGHT PLAN DATA, DEPARTURES, HANDOFFS
WEATHER
WEATHER NOAA
SATELLITE PICTURES
ACTIVITY FORECASTS
CANADIAN EN ROUTE FACILITIES
MILITARY BASE OPERATIONS OFFICE
AIRLINE DISPATCH OFFICE
NWS
NOTE AIRCRAFT, AVIONICS, AIRBORNE SYSTEMS AND COMMUNICATIONS MEDIA ARE NOT INCLUDED
FIGURE 1
CURRENT (1980) ATC SYSTEM CONFIGURATION

FIGURE 1

NEAR TERM (1980-1983) ATC SYSTEM CONFIGURATION

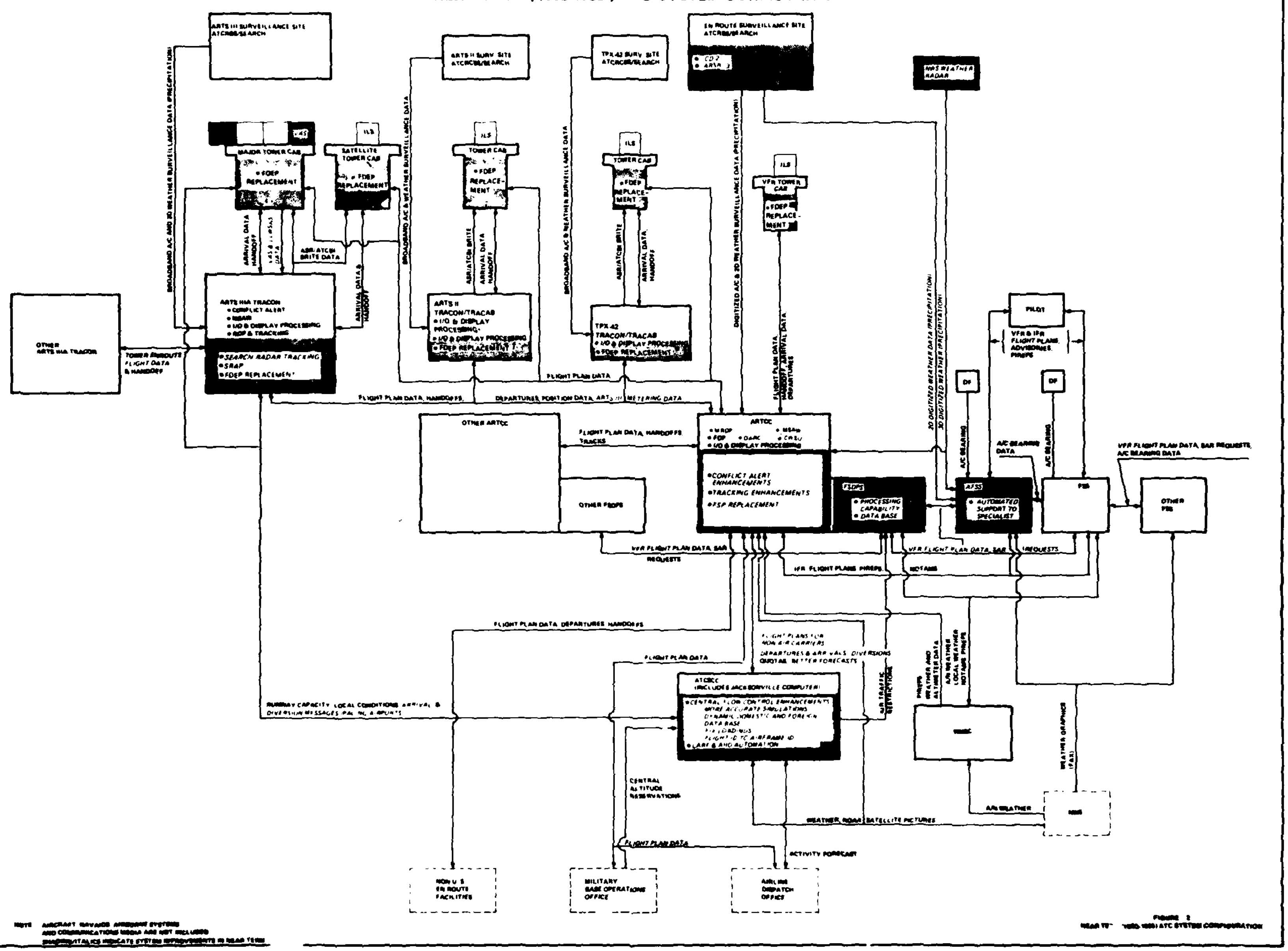

FIGURE 2

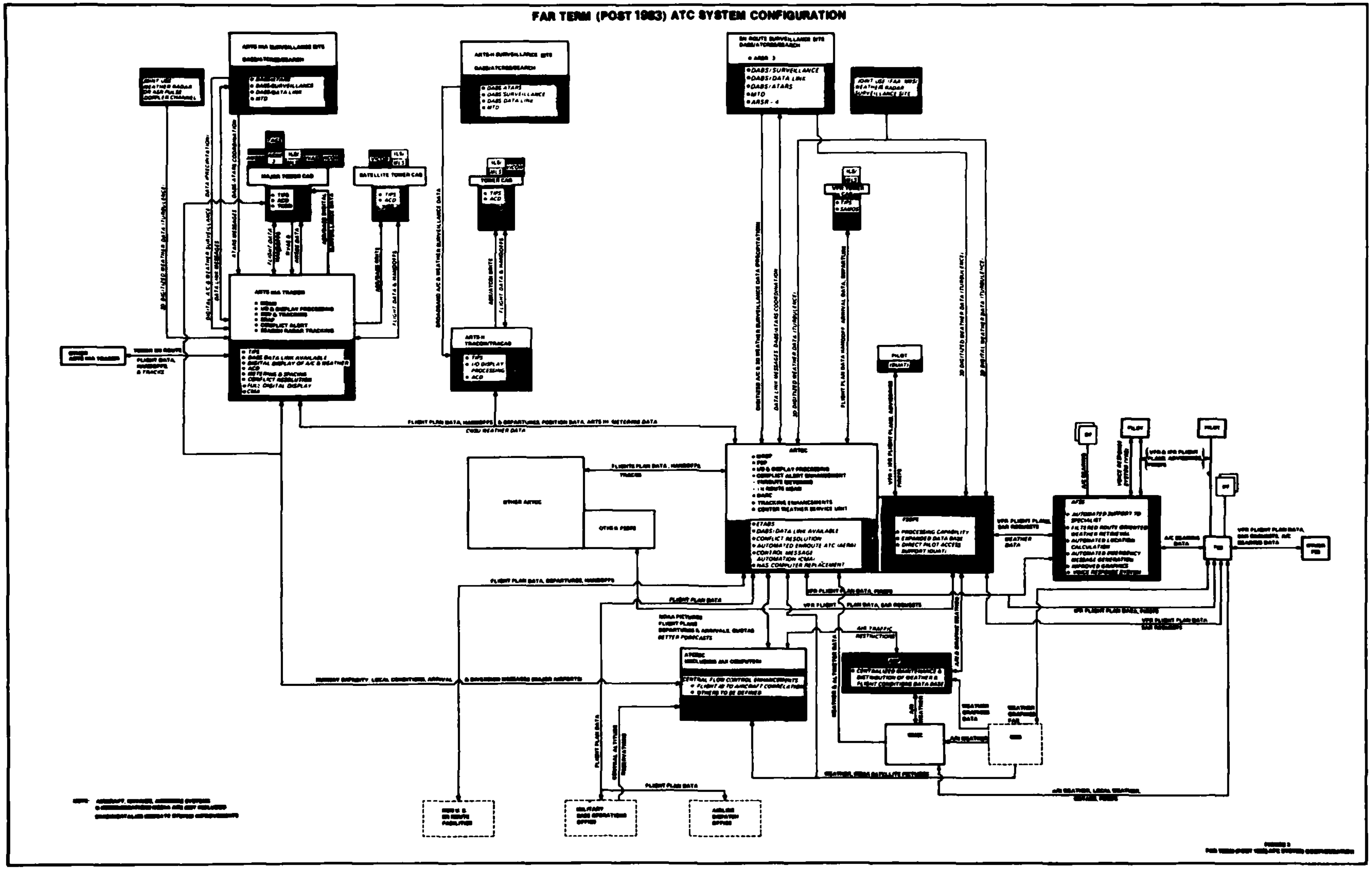
FAR TERM (POST 1983) ATC SYSTEM CONFIGURATION
ARTS III A TRACON
TIPS
DABS DATA LINK AVAILABLE
DIGITAL DISPLAY OF A/C & WEATHER
ACD
METERING & SPACING
CONFLICT RESOLUTION
FULL DIGITAL DISPLAY
CSMA
SATELLITE TOWER CAB
TOWER CAB
ARTS-II TRACON/TRACAB
I/O DISPLAY PROCESSING
ARTS-II SURVEILLANCE SITE
DABS ATARS
DABS SURVEILLANCE
DABS DATA LINK
MTD
EN ROUTE SURVEILLANCE SITE
ARSR - 3
DABS/SURVEILLANCE
DABS/DATA LINK
DABS/ATARS
ARSR - 4
JOINT USE (FAA/ NWS) WEATHER RADAR SURVEILLANCE SITE
FLIGHT PLAN DATA, HANDOFFS, & DEPARTURES, POSITION DATA, ARTS III METERING DATA
CWSU WEATHER DATA
OTHER ARTCC
OTHER FSDPS
ETABS
DABS/DATA LINK AVAILABLE
CONFLICT RESOLUTION
AUTOMATED ENROUTE ATC (AERA)
CONTROL MESSAGE AUTOMATION (CMA)
NAS COMPUTER REPLACEMENT
FSDPS
PROCESSING CAPABILITY
EXPANDED DATA BASE
DIRECT PILOT ACCESS
SUPPORT (DUAT)
PILOT
(DUAT)
WEATHER DATA
FLIGHT PLAN DATA, DEPARTURES, HANDOFFS
FLIGHT PLAN DATA
AIR TRAFFIC RESTRICTIONS
FLIGHT PLAN DATA
CENTRAL ALTITUDE RESERVATIONS
FLIGHT PLAN DATA
PILOT

FIGURE 3

VISUAL CONFIRMATION OF VOICE TAKEOFF CLEARANCE

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BIOGRAPHY

George A. Scott is the Acting Chief Flight Service Station Operations Section, System Development Division. His career in aviation began back in 1948, with a U.S. Navy air search and rescue group stationed in Honolulu, Hawaii. In 1953, he joined the Civil Aeronautics Administration serving as an air traffic controller in the Indianapolis Air Route Traffic Control Center. He transferred to the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N.J., in 1959, where he was involved in numerous ATC simulations, test and evaluation programs. Since 1965, he has been with the Systems Research and Development Service in Washington, D.C.

ABSTRACT

On March 27, 1977, one of the most tragic airport accidents in the history of aviation occurred on Tenerife Island, Spain, killing some 581 people. The probable cause of the accident was a verbal misunderstanding of control instructions between the pilot of the departing aircraft and the airport tower controller. This paper addresses a system wherein a second human sensory stimulus is used to complement the air traffic controllers verbal departure clearance, namely a VIsual CONfirmation (VICON). Included herein are the basic system requirements, a preliminary system configuration, and a test and evaluation program.

Initial testing of a developmental VICON system at the National Aviation Facilities Experimental Center (NAFEC) in April was completed in June 1978. Follow-on field testing and appraisal, conducted at the Bradley International airport, Windsor Locks, Connecticut, was completed in March 1980.

BACKGROUND

During the past several years there have been several aircraft collisions on the surface of airports and many near misses. Analyses of these incidents has indicated that the probable causes involved controller and pilot judgment of runway usage in takeoff, landing and runway crossing operations. At present, runway utilization generally involves the use of a single human stimulus for receiving air traffic control instructions, that of hearing a voice instruction on the aircraft radio.

In a number of the collisions mentioned above, the probable cause of the accident included a reference to, "the pilot not clarifying ATC instructions."

This tends to indicate that present voice (radio) confirmation of runway usage instructions, when not clearly understood by the pilot, can lead to undesirable and, unfortunately, even unsafe operations. It is questionable whether additional voice confirmation of runway utilization instructions (e.g., repeating the issuance or acknowledgment of a clearance, more detailed instructions such as runway identification, etc.) would be as effective in gaining the attention (and hopefully eliminating misunderstandings) of controllers and pilots as the use of a second, independent human sensory stimulus to positively confirm the voice instruction.

The VICON program was initiated in 1977 to determine whether or not visual confirmation of controller voice instructions as they relate to runway operations is feasible, and whether such confirmation can be integrated into the present ATC system. In developing the VICON system, the following factors were considered:

1. The confirmation system shall be used as a standard procedure for all takeoffs at airports where there are FAA operational towers, including single and multiple runway airports, and takeoffs at taxiway intersections as well as end of runway takeoffs.

2. The visual reference shall be conspicuous to pilots of all types of aircraft, other then helicopters, prior to takeoff and should have minimal impact on pilots of landing aircraft.

3. The use of the confirmation system should have minimal impact on pilot and controller procedures and on airport capacity.

4. For the controller, a means of activating

and verifying the activation of the visual signal shall be collocated, should be readily accessible to the controller and separate from other lighting controls.

5. The visual signal shall be distinguishable by the pilot from other visual aids in takeoff areas including displaced threshold areas and shall meet current airport siting criteria for runway lighting systems.

6. If the takeoff visual confirmation concept proves to be operationally feasible and beneficial, it may be used as a basis for a similar visual confirmation system for runway crossings.

SYSTEM DEVELOPMENT AND TEST

As presently defined, the basic components of the VICON are a cluster of three green flashing signal lights located adjacent to the runways at takeoff locations and a system control panel located in the tower cab. These two components are connected by either hardwire or radio control links. See Figure 1.

To determine if a visual signal confirming a takeoff clearance is operationally acceptable and technically reliable, a two-phase development/evaluation program was selected. Phase I, which was conducted at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, was designed to provide initial system development and operational testing; Phase II involves the procurement, installation, testing, and evaluation of a total VICON system at the Bradley International Airport, Windsor Locks, Connecticut.

Phase I Test Environment - NAFEC

To carry out the initial technical and operational tests of the VICON system, runway 13, 31 and taxiway India (Figure 2) at NAFEC was selected to serve as the test location. Also shown in Figure 2 (large circles) are locations of the lights tested during the Phase I effort. Of several luminaries tested, the clustered PAR-56 three light configuration shown in Figure 3 was the most effective. The light cluster was located on the left hand side of the runway, in line with the runway edge lights, approximately 500 feet from the runway threshold or taxiway intersection (one light aimed across the runway, one diagonally down the runway and a third light aimed parallel to the runway). They are easily viewed from the departure positions. Because of its pulsating feature and high intensity lamp otuput they are not confused with other airport lights. Operation of the VICON lights was accomplished through the use of a control panel located in the Atlantic City (ACY) tower cab. As shown in Figure 4, the panel layout is a representation of the ACY runway and taxiway layout and contains several controls for activating the various VICON operational functions.

Once some minor problems (frozen earth and electrical grounding) were resolved, the hardwire system, connecting the control panel with the VICON lights on runway 13/31 and taxiway India, worked well. After some debugging, the radio link also used for linking the control panel with the lights, worked satisfactorily.

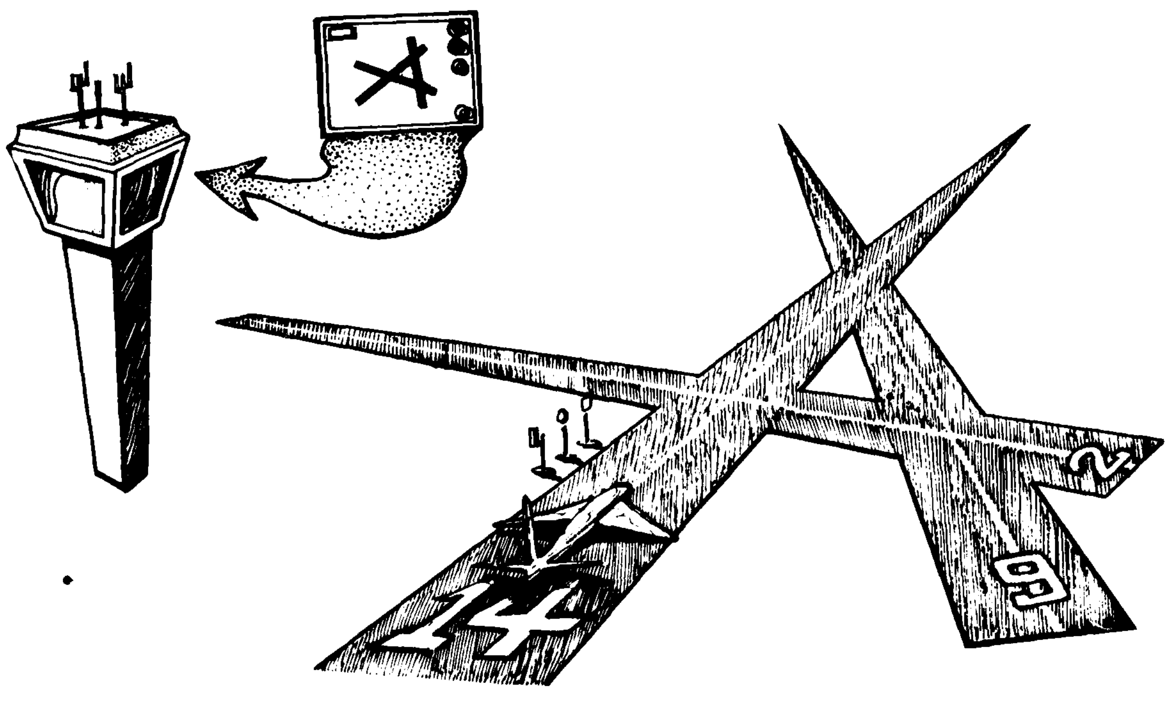

Figure 1. VICON System

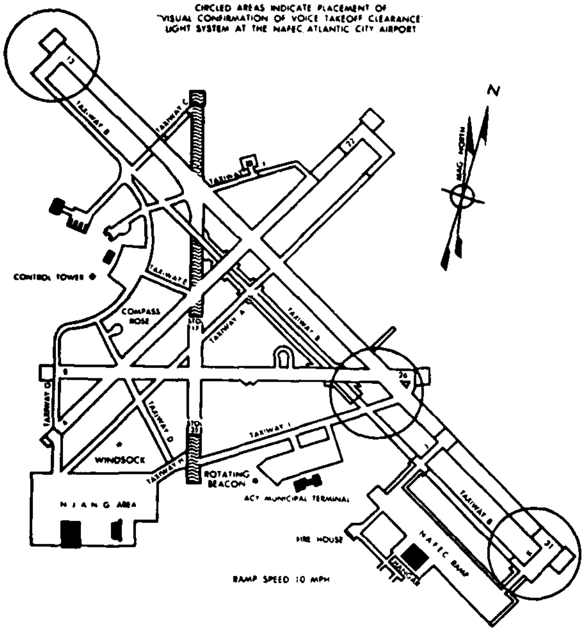

Figure 2. Atlantic City/NAFEC Airport

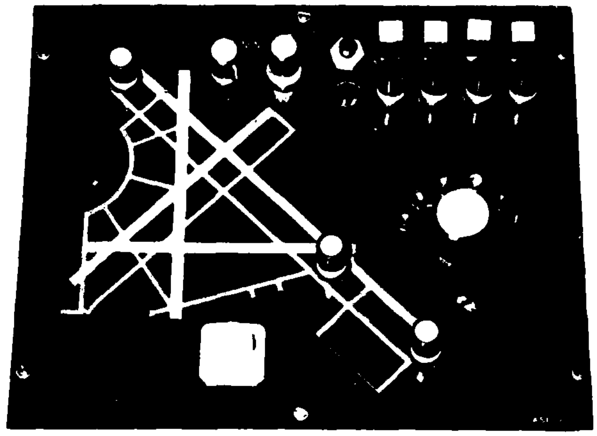

Figure 4. Phase I VICON Tower Control (Mimic) Panel

Figure 3. VICON Light Cluster

An integral part of the Phase I development and test activity was to determine the best technique for automatically deactivating the VICON lights once they had been activated by the controller. (They need to be extinguished so that a following aircraft does not interpret the light to mean that he was issued a takeoff clearance.) Of those tested, an automatic timer (a countdown deactivation device) and a microwave sensor intrusion device performed satisfactorily. An inductive loop system (buried in the runway) had a tendency to become unreliable whenever a change of weather occurre

A major concern in Phase I was that of lamp intensity under varying degrees of meterological conditions and day/night operations. The VICON lights must be bright enough to be seen during sunny days (with the sun shining directly into the lens) and controllable (to a lower intensity) at night so as not to cause glare in the pilot's eyes. Results of the tests indicated that two intensity setting techniques, automatic control through the use of a photocell, and a two position manual switch (high and low) are desirable and need to be selectable from the tower cab.

Phase II - Test Environment - Bradley

Based on the Phase I operational/technical evaluation at NAFEC, a complete VICON system was installed on all runways at the Bradley International Airport (BDL), Windsor Locks, Connecticut. A six month field appraisal program started in October 1979 was completed in March 1980. BDL was selected for the following reasons:

1. Traffic load and distribution representative of moderate size commercial operation, including

international, national, shuttle, general aviation and some military flights. Compares to Orly Field, Paris, France in number of airport operations.

2. Sufficiently complex runway configuration to provide meaningful demonstration of VICON system effectiveness in maintaining traffic flow.

3. User personnel (pilots and controllers) with favorable, neutral pretesting attitudes.

4. An airport administration that supported the objective of the evaluation program.

The FAAs New England Region developed site plans and specifications from their BDL field survey, and awarded a contract for field preparation i.e., cable trenching, building equipment pads, laying cables. NAFEC installed and checked out all of the required VICON hardware. Following installation and acceptance of the system, NAFEC commenced the technical and operational test and evaluation exercises. This operational /technical testing at BDL was most vital, for it represented the VICON system and associated conceptual procedures that will be considered for use throughout the country. For this part of the overall VICON test and evaluation task, all of the six runway ends and the fifteen intersections with taxiways at BDL (Figure 5) were equipped with the VICON light cluster configuration (Figure 3) developed in Phase I. A block diagram of the BDL VICON system is depicted in Figure 6.

Previous tests of airport traffic signal lights (Reference 1) have provided several very important conclusions: (1) Any device placed in the tower cab that diverts the controller's attention away from his primary job of visually controlling traffic could lead to an unsafe situation; (2) A complicated, complex control panel located in a less than optimum location is not acceptable (most tower cabs have very little space, especially at the local control position, for installing additional control panels); (3) At the larger busy airports, the addition of

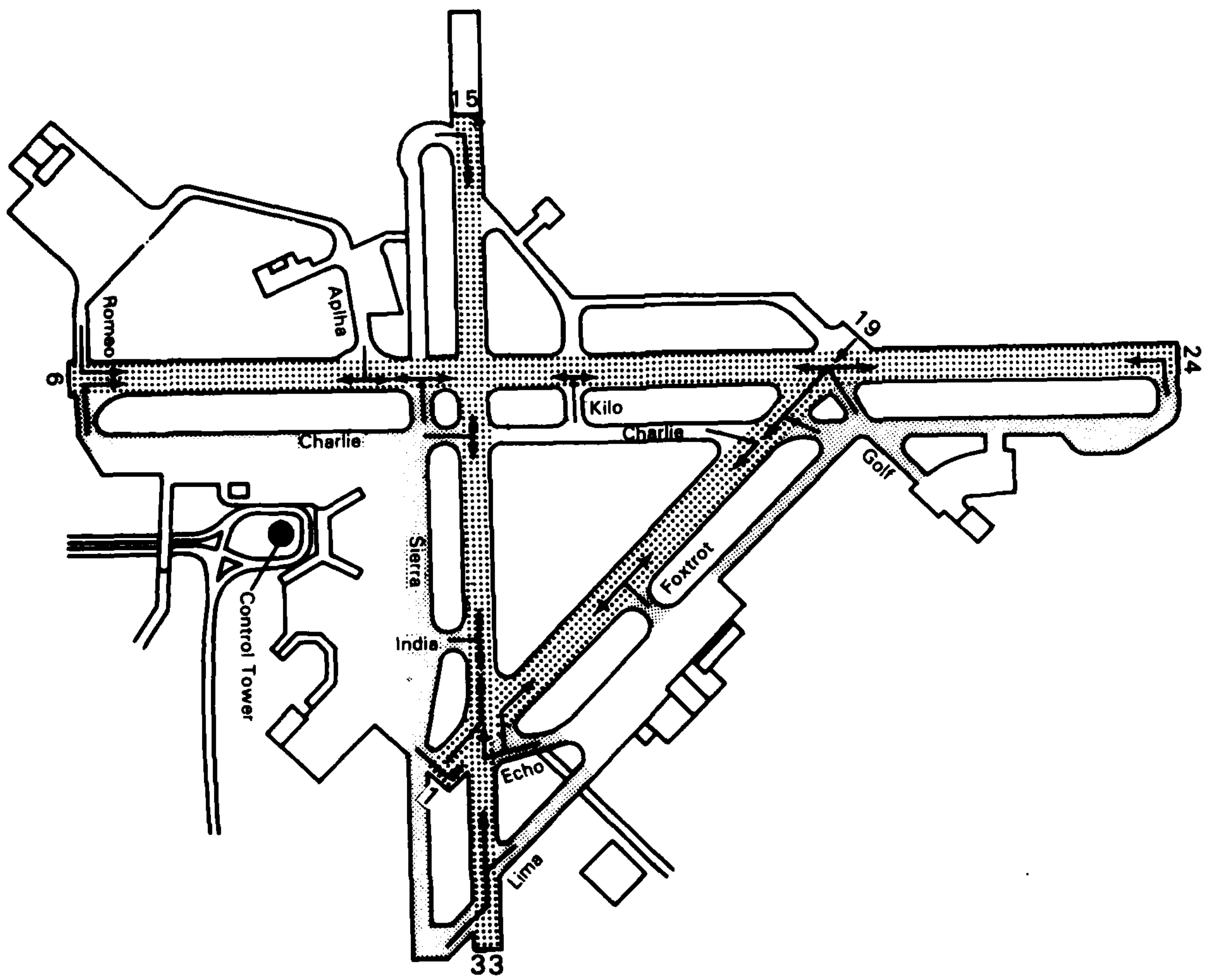

Figure 5. Bradley International Airport, Windsor Locks, Connecticut

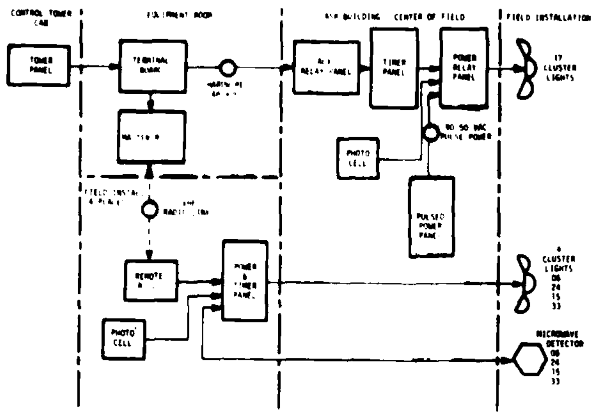

Figure 6. VICON Installation, Bradley International Airport

control personnel may be necessary (4). The entire system must be technically reliable.

Two types of control panels were tested at BDL. A mimic panel, representing the layout of the BDL runways and taxiways, shown in Figure 7, and

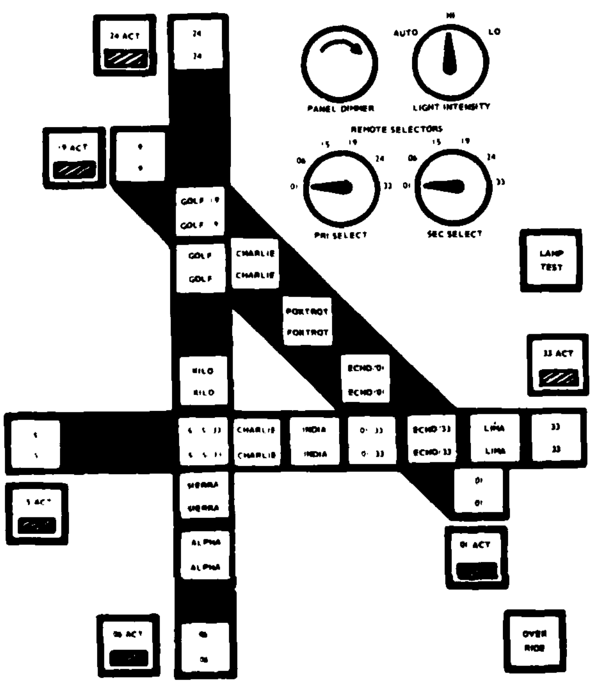

Figure 7. Bradley VICON Mimic Control Panel

a matrix panel as shown in Figure 8. As in Phase I, the remote control panel, a part of the main control panel, was evaluated in conjunction with each console mounted main panel. This switch allowed the controller to move freely about the tower cab without having to return to the main console mounted control panel each time an aircraft was cleared for takeoff.

As in Phase I, the VICON control panel in the tower cab was interfaced with the VICON lights on the field by both hardwire and radio control links. Light intensity was automatically controlled by a photocell or a manual two position (Hi/Lo) override. Extinguishing the lights, once they were activated by the controller, was automatically accomplished through the use of the microwave system at the ends of runways 6/24 and 15/33 and a system timer at all of the other runway ends and intersections.

Phase II Test Methods

By the time the VICON system was installed and ready for test at BDL, the variables to be evaluated had been reduced to a very minimum. Most of the changes were simply minor adjustments to the lights (e.g., angles, louvers, etc.) located on the field and minor modifications to the tower cab control panels. During the Phase II test period a technical log was maintained on the performance of each VICON subsystem so that at the end of the test period, the reliability of each component could be determined. The BDL technical evaluation data will be used to determine: (1) system reliability; (2) cost effectiveness (3) installation criteria and maintenance details.

The operational evaluation at BDL encompassed the basic technique used during the Phase I effort; i.e., pilot and controller reactions to the system. Individual questionnaires and group interviews for these users were prepared and administered only after extensive efforts to familiarize the controllers and pilots with the VICON system had been accomplished. Objective data for this phase of the program, such as air traffic delays, aborts, communication repeats, workload, etc. was also collected.

Phase II Data Collection

Information about the controller's attitude toward system effectiveness encompassed four areas of concern:

1. The capability of a properly designed and operating VICON system to provide the pilot with confirmation information comparable to currently used radio only techniques.

2. The degree of confidence in the accuracy and reliability of VICON performance to the extent that the safety of surface traffic was maintained.

3. Reactions to the installation and suggestions for modifications and improvements.

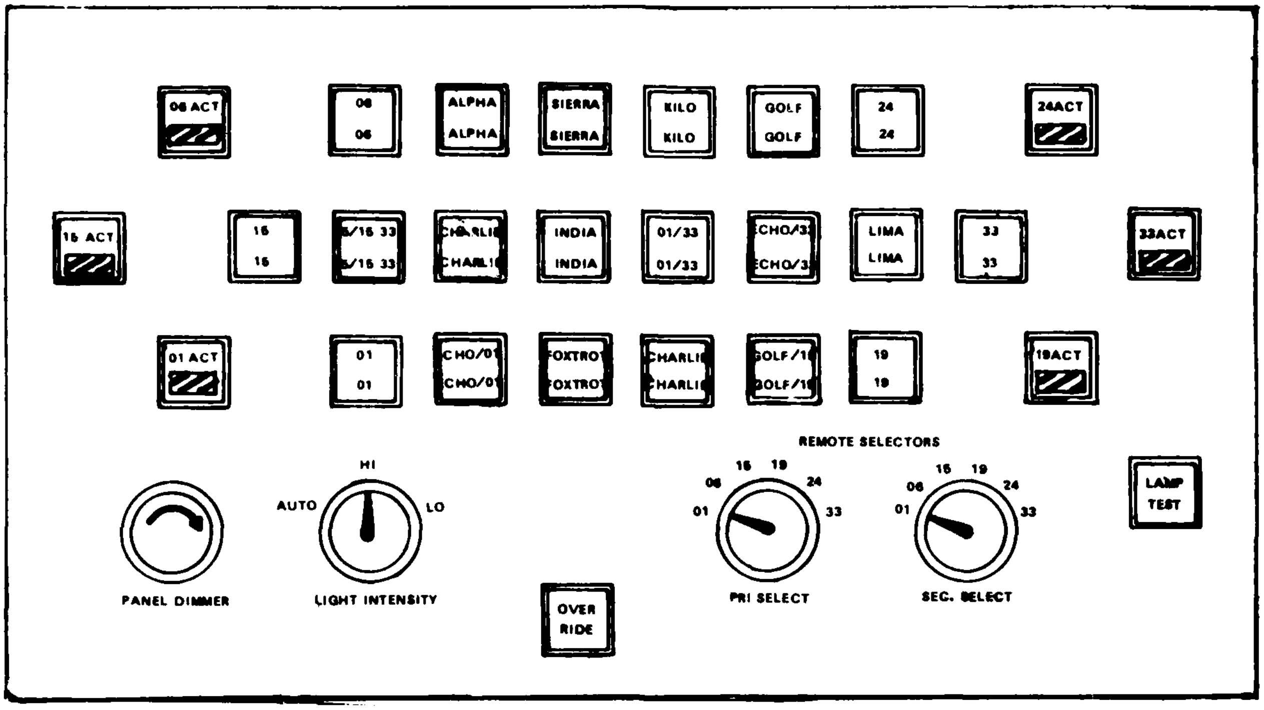

Figure 8. Bradley VICON Matrix Control Panel

This included technical items such as panel location and size, switch sizes, etc., and such operational items as the requirement for the procedures pertaining to an additional VICON controller.

4. Subjective reaction on affect to controller workload listed above will be summarized to obtain the general consensus of controllers concerning the VICON. Where questions dealing with specific items of interest; e.g., safety, visibility limitations or conflicting message resolution, differ significantly in the number of favorable and/or unfavorable responses, these differences will be used as diagnostic tools for system improvement, or as trade-offs in the overall assessment of VICON versus other methods of confirming takeoff clearance.

Analysis of these results will pay particular attention to the experience of the controller responding and any change in attitude or response which occur many times (repeated submission) during the test schedule.

Since the pilot will be the ultimate beneficiary of the system to be used for takeoff clearance information, his responses are critical to acceptance of the VICON concept. Information concerning four areas of pilot attitude were obtained through the use of individual questionnaires and group interviews.

1. Did the takeoff clearance confirmation signal reduce or increase pilot workload during normal operating conditions?

2. Was sufficient information provided by the visual signals to maintain traffic flow efficiently and safety without excess radio contact?

3. Did the use of the signal permit safe takeoff clearance confirmation under severely limited visibility conditions?

4. Was there a positive overall reaction to the VICON signal concept and are there suggestions for modification and improvements?

The data obtained from the pilots will be treated in essentially the same manner as that derived from the controller. In analyzing these data, particular attention must be paid to any differences in response associated with aircraft type, familiarity with airport, and nationality (language facility) of pilots.

SCHEDULE

Testing of the Phase I NAFEC VICON developmental system was completed in June 1978. The BDL VICON in-service test and evaluation which started in October 1979, was completed in March of 1980. Phase II data reduction and analysis, which is currently underway, should be completed by August 1980.

SUMMARY

The technical engineering data and the operational data gathered during the planning, installation, test and evaluation of the VICON system at NAFEC and BDL will be used by the FAA's operating services to make an implementation decision. If the tests show that the VICON can be integrated into the present ATC System and would improve safety and the decision is made to implement the system nationwide, then a technical data package will be developed for use by the Airway Facilities Service in the implementation program..

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AVIATION WEATHER SYSTEM PROGRAM

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BIOGRAPHY

John Hinkelman is in the Systems Development Division, Systems Research and Development Service of the Federal Aviation Administration (FAA) and is responsible for Aviation Weather System (AWES) engineering and integration. He is a jet pilot, received a BS in Meteorology from the U.S. Naval Postgraduate School in 1954 and an MS from the University of Maryland in 1963. He was a member of the FAA National Airspace System (NAS) System Design Team from 1961 to 1963, and prior to returning to the FAA in 1976 was Manager of the Research Aviation Facility at the National Center for Atmospheric Research in Boulder, Colorado, where he was responsible for flight research in thunderstorm turbulence and jet-stream Clear Air Turbulence (CAT) areas.

ABSTRACT

Aviation weather support requirements have historically been satisfied on a problem by problem basis with little attention being given to an overall integrated system concept. It is readily apparent that more basic observational data are required, faster communications and dissemination techniques are needed and labor intensity must be reduced. In an effort to resolve both the near-term and long-term problems of aviation weather support, the FAA has initiated a program for the evolutionary upgrading of aviation weather services. The new Aviation Weather System (AWES) architecture will consist of four basic functional areas: data acquisition, data processing, communications, and display/presentation. Within each of these areas are a variety of required development activities which will be coordinated and integrated to provide a cost-effective total system capable of requirements. This paper describes the system in terms of its operational capabilities and outlines the technical engineering development program to be pursued by the FAA.

BACKGROUND

The purpose of the Federal Aviation Administration's (FAA) aviation weather support system is to provide accurate, timely, and operationally meaningful weather information to National Airspace System (NAS) users with special emphasis on the identification and description of hazardous weather situations.

Today's system is limited with regard to the amount of information available to it, its ability to rapidly digest and disseminate those data which are operationally significant, and its capability to provide NAS users with real-time reports of weather phenomena capable of impacting the safety and/or efficiency of aviation operations. The critical elements of the existing system architecture are its high degree of labor intensity and its relatively slow communications links. Unless the basic system is updated, an increase in available information, for example, would serve only to compound the problems associated with communications, filing, sorting, analyzing and delivering meaningful products to the users in a timely manner.

In recognition of this need for a new aviation weather support system architecture, the FAA, in mid 1977, initiated the development of a plan for the evolutionary upgrading of aviation weather support services between now and the year 2000. The evolutionary approach was taken in an effort to minimize the disruptive effects of a step-function changeover from present operational procedures and to take full advantage of ongoing system improvements in the near-term (now 1980) period. The Aviation Weather System Preliminary Program Plan was completed and approved by FAA Management in early 1978 and has been coordinated with the other Federal Agencies--National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and Department of Defense (DOD) having related aviation weather responsibilities and programs.

OPERATIONAL OVERVIEW

The AWES will provide increased operational capabilities for effectively reducing the adverse effects of weather phenomena throughout the NAS operating environment. Reliable, more accurate and more complete information, rapidly distributed in forms and formats directly useable by pilots, controllers, Flight Service Station (FSS) specialists, etc., in their decision making processes, will significantly improve the safety and efficiency of NAS operations. These improvements will be accomplished through:

1. Improved radar detection, identification and tracking of severe weather echoes.

2. An increase in the number and frequency of surface observations and an improvement in their reliability through automation and quality control.

3. Automated collection, processing, and distribution of pilot reports (PIREPS).

4. A reduction in the time required to deliver operationally critical weather information to pilots and other NAS users.

5. Automated tailoring of weather information to render it more suitable for direct operational application.

6. The provision of real-time hazardous weather avoidance assistance to pilots.

7. Improvements in the accuracy of aviation weather forecasts through automation and quality control.

Each of the above listed capabilities is readily attainable within existing technology. As each of these capabilities is pursued, it will be incorporated as an interactive element of a larger integrated system--the AWES--which in turn, will function effectively in support of the NAS. The inter-relationships are depicted in Figure 1 and 2. In this regard, the following general concepts have been adopted for the improved system:

1. The major focal point for real-time collection, monitoring, interpretation and dissemination of hazardous weather information will be concentrated at the Air Route Traffic Control Center (ARTCC) Whather Service Unit (CWSU).

2. The most time-critical IFR weather information, dissemination and display functions will be concentrated at terminal facilities.

3. The System Command Center (SCC) will perform those weather-related functions associated with strategic planning and will conduct certain quality control checks of weather services provided.

4. The Flight Service Station (FSS) system's capability to provide essential briefing and inflight services (primarily to visual flight rules (VFR) operations will be enhanced and automated.

The system will use both Air Traffic Control (ATC) and weather radars to detect and track severe weather. Current weather detection capabilities will be enhanced initially by improving both en route ARSR and terminal ASR radars and by remoting National Weather Service (NWS) WSR radar data for FAA Center, Terminal (TRACON) and FSS facilities. ARSR data will also be remoted to certain FSSs. A new national Doppler radar system to be implemented in the mid-term period (1981-1984) will provide a marked improvement in the operational value of weather radar by detecting severe turbulence areas and by displaying these data directly on controllers' displays. It is anticipated that the motion of the turbulent areas can be predicted for very short periods of up to 30 minutes and the projected tracks also displayed at the controller's option.

Pilot reports of hazardous weather will be collected through both the CWSU and the FSS En Route Flight Advisory Service (EFAS) positions and mutually exchanged for rapid dissemination to aircraft inflight, for preflight briefing, and for dissemination to the NWS.

An automated data collection, processing, distribution, and display sub-system will be developed for real-time dissemination of PIREPS, observations, advisories and short period forecasts to pilots, controllers and FSS specialists.

Surface (airport) weather observations will be taken and disseminated automatically at airports with approved instrument approaches but having no FAA facilities. At FSS and ATC tower sites, critical portions of the observations will be automated, augmented by humanly observed data, and automatically transmitted to users. Automated surface observing components will be modular in design to provide for installation flexibility and upgrading as required. Special detection systems for wind shear will be utilized at selected major terminals. Real-time weather satellite (GOES) cloud cover photographs will be available at the SCC, at each Center and at FSS facilities for briefing, analysis, strategic planning and hazardous weather avoidance applications.

The system will provide for rapid generation and dissemination of reliable, very short period (0-30 minutes) forecasts of hazardous weather for direct pilot and controller use. Accurate, short period (up to 4 hours) forecasts are required to support flow control activities both at the Centers and the SCC. This capability assumes a general NWS short range forecast product improvement over the next 10 years.

The 20 CWSUs (one at each Center) will perform centralized ATC weather interpretation and dissemination functions. NWS meteorologists at these positions will interpret data for use by Center, TRACON and tower controllers. Radar severe weather information will be displayed real-time on controllers' Plan View Displays (PVD) and other significant hazardous data will be displayed rapidly for dissemination to pilots.

The CWSU will be the tactical focal point for the collection of IFR PIREPs and special severe weather alerts and for their dissemination to appropriate terminals and FSSs. An appropriately programmed automatic weather data storage and display system will provide the CWSU with direct access to all surface observations, upper air data, terminal forecasts and graphics data, and

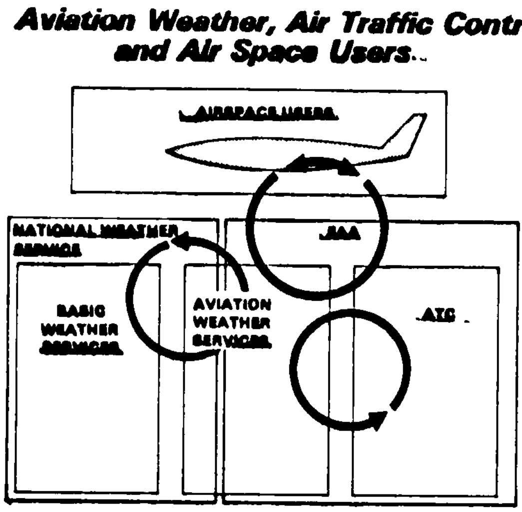

Figure 1

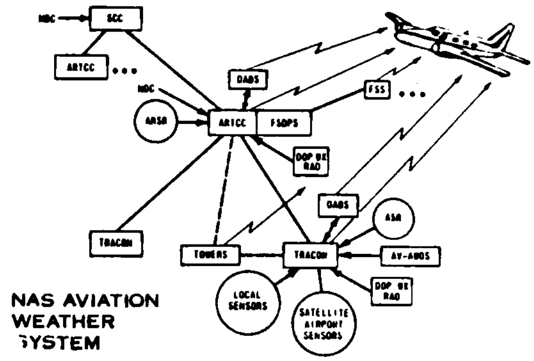

Figure 2

and severe weather information as an entry point for PIREPs and other special data.

Severe weather data from either improved ASR or Doppler Weather radar will also be displayed on the terminal area controllers' displays and remoted to BRITE display-equipped towers. Terminal area observations and other alphanumeric data will be displayed at TRACONs and local observations at towers. The center and terminal displays will be modular in design to provide for flexibility and economy in implementation. FSSs will also have displays to support briefing and EFAS functions. These displays will have access to extensive data bases to support these functions. Automatic Voice Response System (VRS) implementation in the mid-term period will enable automation of Pilot Automatic Telephone Weather Answering Service (PATWAS), Transcribed Weather Broadcast (TWEB) and certain pilot self-briefing functions.

The AWES will provide automated data processing support to each CWSU, major terminal area, and Level III FSS to support the data distribution and management functions associated with providing alphanumeric (A/N) displays at centers and TRACONS, automatic generation of very short range severe weather forecasts (extrapolations) for controllers, and to meet FSS broad data base requirements.

The supporting communications network necessary to provide adequate rapid transfer of system data will ultimately utilize an optimum combination of NWS National Distribution Circuit (NDC) and FAA National Automated Data Interchange Network (NADIN) II 2400/4800 baud networks. The SCC and 20 Centers will have Automation of Field Operations and Services (AFOS) access equipment and, in general, the FAA will internally utilize NADIN II. Since NADIN II will not be implemented in the near-term, continued FAA use of Service A and facsimile on an interim basis will be necessary at non-automated facilities. The ultimate AFOS/NADIN interface configuration will be determined by a detailed system study of ATC and FSS configuration and loading requirements and joint interagency (NWS/FAA) plans. Figure 3 is a simplified functional block diagram of the improved system.

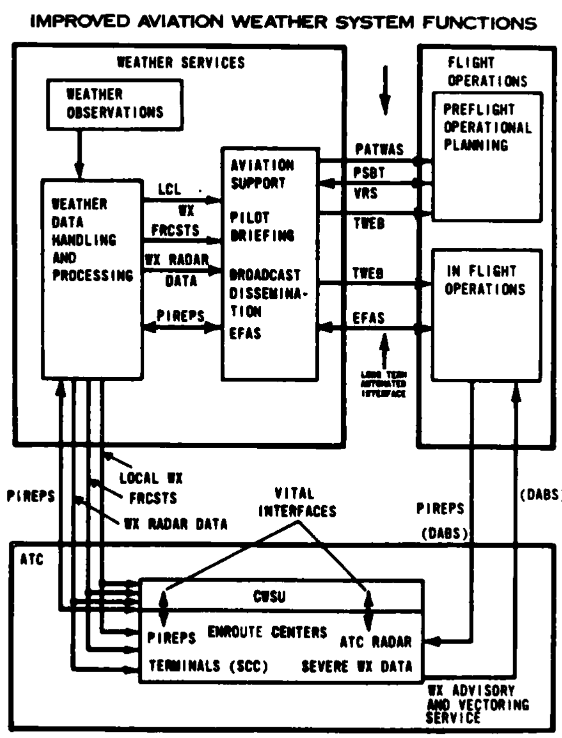

Figure 3

ENGINEERING DEVELOPMENT OVERVIEW

The AWES architecture will rely heavily on automatic data collection. Medium speed (2400-9600 bits/second) digital communications, automated data base management and product generation, cathode ray tube display and automatic ground to air communications. A totally distributed, rather than a centralized or regionalized, data processing concept will be employed to enhance system responsiveness to users and to avoid the potentially catastrophic effects of single site failures.

The key characteristic of the AWES will be its engineering unity. That is, AWES will be a totally integrated system rather than a collection of pseudo-independent elements each of which provides its own peculiar output to the NAS users. The system will collect all weather data available to it, process this data into operationally meaningful products and deliver these products in real-time to pilots, controllers, FSS specialists, etc. Thus, the system can be subdivided into four basic functional areas as decribed below.

Presentation/Display

This functional area focuses on the characteristics of the information to be provided to the system users. As such, it is the most critical area in the system design. For each user; e.g., the pilot, center controller, TRACON controller, FSS specialist, CWSU meteorologist, etc., such things as informaton content, form, format, and presentation/display control capability must be determined. These, then, become the total system performance requirements and all other system elements can be justified only in terms of their contributions to the presentation/ display objectives. An important aspect of the presentation display functional area is the requirement that both the in-flight pilot and the controller have accurate, timely, and compatible weather information in order that each can make an intelligent contribution to the coordinated solution of weather related operational problems.

Each of the system users will have slightly different information presentation/display requirements and each will need both an A/N and a graphic capability. The FSS requirements have already been reasonably well defined as a part of the ongoing FSS Modernization Program which is an integral part of the overall AWES. The CWSU and SCC requirements will be satisfied through direct access to NWS AFOS System, the Modernized FSS System, GOES Satellite Recorders and Remoted Radar (both weather and ATC) displays. The most critical users are, however, the pilots and controllers (center, TRACON, and tower). In the near-term the pilot will rely on on-board capabilities, automatic weather information broadcasts, controller supplied information and the FSS En Route Flight Advisory Service (EFAS). In the mid and long terms the automated DABS ground-to-air system will enhance this weather information collection capability.

The presentation/display requirements of controllers are very similar regardless of whether they are in a center, a TRACON, or a tower, but so also are the constraints. The controller's graphic requirements consist primarily of outlines of storms and turbulent areas as detected by the various system radars, together with coded indications of severity. In order to avoid the time consuming and tiresome task of having to mentally register the information on two separate displays, the radar derived weather graphics information should logically be superimposed directly on the controller's ATC display. To prevent interferring with the controller's primary function of providing for the safe separation of aircraft, controller operated fading, texturing and/or quick-look weather data display control capabilities will be examined to resolve this problem. The ATC alphanumeric weather data display capability will consist of certain forced operational critical information with simple instantaneous access to a larger inventory of products. Display media options include the Electronic Tabular Display System (ETABS), Terminal Information Processing System (TIPS) a separate A/N CRT and a sterile area of the controller's ATC display.

Data Acquisition

Data acquisition is next in operational importance since it is the raw input information which dictates the content and operational validity of the output products. The FAA currently has a family of modular automatic surface observing systems under development (AV-AWOS, ALWOS, WAVE, SAMOS) which will provide synoptic weather observations at airports, and in addition, provide current observations at any time upon user request through the communications subsystem.

Automatic broadcast of observation data to pilots in flight is also a planned feature of the AWES.

A developmental model Aviation Automated Weather Observation System (AV-AWOS) was subjected to a full scale operational test at Patrick Henry International Airport, Newport News, Virginia and the results indicate that automated aviation weather observations are practical provided low cost cloud height and visibility sensors are developed. The FAA and the NWS are jointly pursuing these developments. The primary constraints in this area are the large numbers of units required, coupled with the purchases and maintenance costs per unit. Maintenance requirements must, of course, be minimal, especially at unmanned sites.

The FAA and the NWS are also pursuing the development of low cost automated observing systems (ALWOS and WAVE) for those 900 plus airports with approved instrument approaches but which presently have no weather observing capability. These systems would have more limited capabilities than the AV-AWOS but will retain the automatic broadcast feature. The initial Semi-Automatic Observing System (SAMOS) installation is in operation at the FAA tower in Clarksburg, West Virginia. This unit provides assistance to the tower controllers who are responsible for taking observations at such locations.

The second major element in the data acquisition area is radar. Neither of the two basic ATC radars, the ASR and the ARSR, are particularly well suited to quantitative measurement of severe weather echoes, although both are more than adequate as general weather detectors. The broad vertical beam of these radars tends to compromise the validity of any quantitative turbulence or intensity calculations. A variety of developments have been completed or are currently underway in an attempt to derive valid weather information from ATC radars. NWS WSR radars are designed for weather detection and echo intensity measurement but are now 20 years old and too often down for maintenance. A variety of video remoting and processing systems are either available or under development for providing near real-time displays of radar weather data from both the FAA and NWS radars at Centers, TRACONs, towers, etc. And for the near-term period, this appears to be the best available solution. For the mid and long term periods a joint FAA/NWS/DOD national Doppler radar system is planned.

Communications

Near-term communications enhancements between the pilot and the ground will focus on more direct pilot access to weather information. In the mid and long-term Voice Response Systems (VRS) and Discrete Address Beacon System (DABS) will be employed for the real-time relay of weather information to and from pilots in-flight. Ground communication of weather information in the AWES will, in the near term, be accomplished via existing FAA teletypewriter circuits (Service A) and through direct interface with the new medium speed (2400 bits/sec., full duplex) NWS AFOS National Distribution Circuit (NDC). In the mid and long-term periods, a combination of the NDC and the FAA's NADIN II, presently under development, will be used. These two circuits will be fully capable of meeting all aviation weather communications requirements for the next two decades.

Processing

As previously noted, the AWES data processing functions will be totally distributed rather than regionalized or centralized. There will be some limited processing at each automated observing site to render the raw data suitable for local application and communication to pilots and other operational facilities. Each Center will have the capability to store a full operational weather data base, to tailor the data for direct application by users within the ARTCC area of responsibility and to service nearby towers and TRACONS. The FSS data base management and product generation functions will also be located at the ARTCCs with limited storage and retrieval capabilities at each Category III FSS. In the near-term the presently manned CWSU positions will be provided with NWS AFOS systems. This capability will then be expanded through the introduction of FSS Data Processing Systems (FSDPS). A further expanded integrated center weather data processing system capable of satisfying all user requirements is the long-term FAA goal.

SUMMARY

The FAA is now in the process of embarking on a major new system development program. The objectives of this effort are to provide enhanced aviation weather support services in the near-term and to establish a basic weather support system architecture which will be capable of satisfying the NAS requirements for weather support over the next two decades. The majority of the system elements required for AWES development are presently available within the technological state-of-the-art. The major challenge, however, is to integrate these various elements into a cost-effective integrated system which will satisfy the broad range of weather support requirements of the entire aviation community.

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CHARACTERIZATION OF THE THUNDERSTORM FOR SAFE AIRCRAFT OPERATIONS

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BIOGRAPHIES

Frank V. Melewicz has been a meteorologist since 1941, primarily as a meteorological officer in the U. S. Navy. He is a graduate of Union College and has done post-graduate work in Meteorology at New York University. He holds a private pilot's license and is a Certified Consulting Meteorologist. His work has been in fog dispersal research and the management of wind shear projects.

Arthur Hilsenrod is a Subprogram Manager in the Aviation Weather Branch. He has a B.S. degree from Long Island University and a M.S. from California Institute of Technology and is a Certified Consulting Meteorologist. He has worked on airport visibility systems, helicopter icing, weather forecasting, sonic boom, and meteorological conditions of urban V/STOL heliports.

James H. Muncy is an Electronics Engineer. He has worked in the field of radar since 1942 with the U. S. Naval Research Laboratory, U. S. Navy and the Bureau of Standards. His latest work in the Aviation Weather Branch is in Doppler, airborne, and ground-based weather radars.

Raymond Colao is presently a Subprogram Manager/Project Engineer on Aviation Weather Systems programs. His B.E.E. degree is from the City College of New York. He has experience in FAA programs from navigational aids systems such as VORTACS to Air Route Traffic Control Center and terminal automation and weather systems. His latest work has been in wind shear detection.

ABSTRACT Thunderstorms represent a threat to the safe operation of aircraft. They frequently result in air traffic delays. The Federal Aviation Administration is supporting activities to eliminate this threat by characterizing the nature and movement of thunderstorms. The thunderstorm hazards to be avoided include turbulence lightning, hail, sudden wind shifts, wind shear and heavy rain. The thunderstorm-produced outflow or gust front is often accompanied by strong low-level wind changes and turbulence which constitute hazards to aircraft arriving and departing an airport. Uncertainty in gust front observation and prediction contributes to loss or damage to aircraft. Discussions on gust front structure are presented as determined from observations obtained from Doppler radar, aircraft, instrumented towers, and standard weather radar. Efforts are being undertaken to improve forecasts of thunderstorms with projections of 10 minutes to 2 hours by processing digitized radar data. Doppler weather radar measures wind fields inside thunderstorms and provides unique velocity signatures associated with tornadic storms.

INTRODUCTION In the U. S. thunderstorms occur in all of the states with the maximum annual frequency of approximately 100 per year in central Florida diminishing to less than 5 per year along the west coast of California, Oregon and Washington. Thunderstorms represent a major hazard to safe aircraft operations. Thunderstorms cause aircraft delays, flight cancellations, diversions and overflights which in turn result in increased costs, increased energy consumption and passenger inconvenience.

IMPACT OF THUNDERSTORMS ON AIRCRAFT OPERATIONS
In 1978, thunderstorms accounted for 28.7% or 14,993 air traffic delays of 30 minutes or more in the U. S. Thunderstorms have been a cause or factor in approximately one-fourth of the non-fatal general aviation accidents due to weather. They have also been a cause or factor in approximately one-third of the fatal general aviation accidents due to weather. For the commercial airlines, thunderstorm/turbulence has been responsible for an average of 8 accidents per year during the period 1960 to 1969 inclusive. In the five year period, 1972 to 1976 inclusive, these accidents have increased to an average of 12 per year.

As air traffic continues to increase in the future, as it has in the past, we can expect more confrontations to occur between thunderstorms and aircraft. The question arises, how can we characterize thunderstorms to determine which ones are safe for aircraft penetration and which ones should be avoided entirely because of the hazards which they pose for aircraft.

FAA THUNDERSTORM CHARACTERIZATION RESEARCH
The Systems Research and Development Service of the Federal Aviation Administration has recently completed research to characterize the nature and movement of thunderstorms. Improved diagnostic techniques for the analysis and timely warning of severe thunderstorm hazards are being developed. Doppler weather radar, ground-based pressure sensors, standard weather radar, satellite information, aircraft observations, avionics and automated meteorological observation stations are being used for this purpose.

To appreciate more fully the scope and importance of this work, we note in Figure 1 a cold front extending from the Great Lakes to Texas on the synoptic weather chart of June 12, 1978 at 7:00 A.M. E.S.T.

A cool polar continental air mass covers the Mid-west and is slowly moving southeastward, gradually replacing the warmer and humid subtropical air mass covering the east coast. The cold front, or zone of discontinuity between these two airmasses contains convective clouds, showers and thundershowers which are proceeding eastward. The synoptic chart does not give detailed information on where the thunderstorm cells are located, their intensity, cloud tops, gust fronts or winds inside the thunderstorm. These detailed characteristics of thunderstorms can be determined with other meteorological sensors such as Doppler weather radar, acoustic echo sounders, satellites, standard weather radar and surface and aircraft observations. This paper will consider the application of these additional meteorological sensors to more fully define and detail the characteristics of thunderstorms for use of pilots and air traffic controllers.

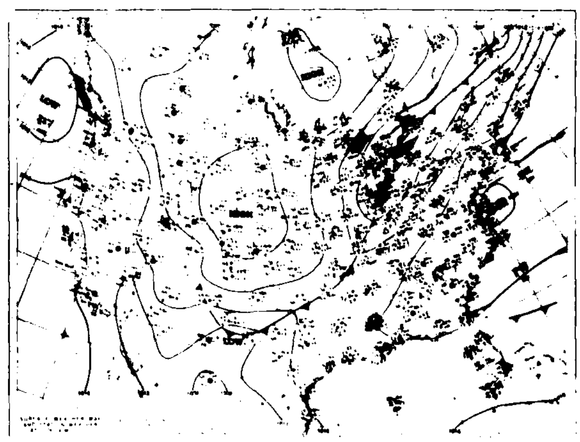

Figure 1. Synoptic weather chart of June 12, 1978, 7:00 A.M. (E.S.T.)

The corresponding satellite picture of June 12, 1978 (Figure 2) taken from the NOAA Geostationary Operational Environmental Satellite (GOES) which is located 23,000 miles above earth shows more clearly the cloud types developing along the cold front with isolated thunderstorm cells in western Tennessee and into Arkansas.

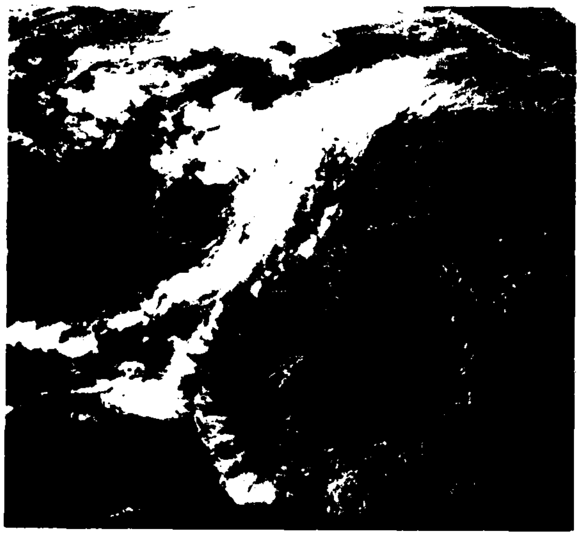

Figure 2. Geostationary Operational Environmental Satellite image of June 12, 1978, 1730 (E.S.T.)

By satellite infra-red imagery, the warmer and colder cores of those thunderstorm cells can be differentiated along the entire cold front, the darker centers being the **colder** temperatures (Figure 3).

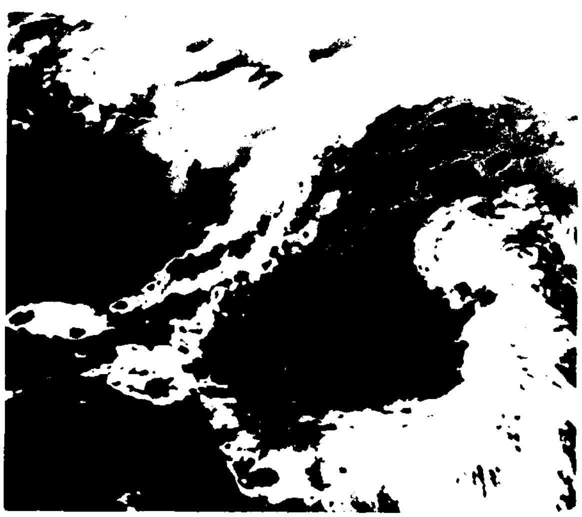

Figure 3. Infra-red image from Geostationary Operational Environmental Satellite of June 12, 1978, 1700 (E.S.T.)

These satellite data give us an analytical tool to determine the size and location of thunderstorms and provide us with avoidance criteria.

A severe thunderstorm is characterized by the unmistakable anvil top and often a roll cloud or gust front at its base. The gust front may extend as much as 10 miles ahead of the thunderstorm center. If the air is thermodynamically unstable and certain meteorological conditions prevail, a tornado may form from the cloud base. The above, then, are the visible parts of the thunderstorm. To determine the invisible portions and inner structure and dynamics of thunderstorms, special instrumentation is required.

The WSR-57 weather radar provides a display of thunderstorm radar reflectivities which are presented in discrete intensity levels (Z values). High Z values are associated with the more severe thunderstorms. Microwave Doppler radar, currently under development, offers a promising method for measuring wind fields, in detail, inside thunderstorms. The Doppler weather radar provides a contour-mapped display of meteorological target velocities in real time. WSR-57 radar echo intensity and Doppler wind velocity must be considered together in analysis and application. By using two Doppler radars at different viewing angles, it is possible to calculate the winds inside of thunderstorms. An example of the use of two S-band pulsed Doppler radars in thunderstorm analysis follows.

On June 8, 1974, a major outbreak of tornadic storms developed in central and northeastern Oklahoma. The Doppler radar display of developing winds is shown in Figure 4(a).

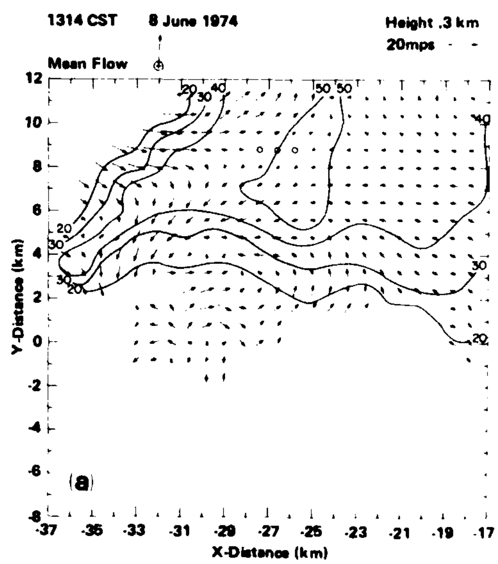

Figure 4(a). Horizontal wind field analysis by Doppler radar of Oklahoma City storm of June 8, 1974

From 1314 C.S.T. to 1421 C.S.T., the storm's velocity structure at .3 Km. elevation formed into a mesocyclone or local low pressure area (Figure 4(b).

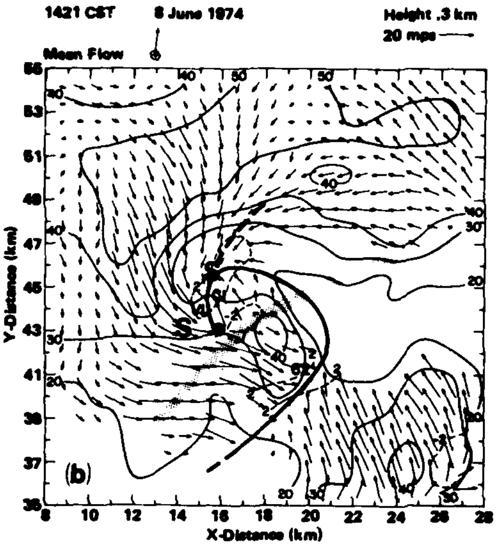

Figure 4(b). Horizontal wind field analysis by Doppler radar of Oklahoma City storm of June 8, 1974

The peak wind shears were found near the mesocyclonic center and are labelled "S". Three tornadoes were spawned by this thunderstorm beginning at 1342 C.S.T. The tornado is shown by the solid circle in Figure 4(b) and the storm damage path is stippled. The heavy line is a thunderstorm gust front and it is within the mesocyclone and near the gust front that the highest wind shear and maximum vertical wind velocities are found. This area is extremely hazardous to aircraft flight.

From 1314 C.S.T. to 1440 C.S.T. reflectivity appendages and hook echoes, which are indicative of the presence of severe thunderstorms and probable tornadoes, were observed continuously in the radar reflectivity patterns on the plan position indicator radar display (Figure 5).

In Figure 4(c), the thunderstorm shows signs of dissipation and the wind discontinuities in the vicinity of the mesocyclone are more diffuse. The low-level convergence of wind flow diminishes and downdrafts are reduced. Peak winds are found at a radius of 2 to 3 Km. from the mesocyclonic center.

It has been found that a tornado is always preceded by a mesocyclone. Mesocyclones which produce tornadoes have smaller horizontal diameters and are taller and rotate faster

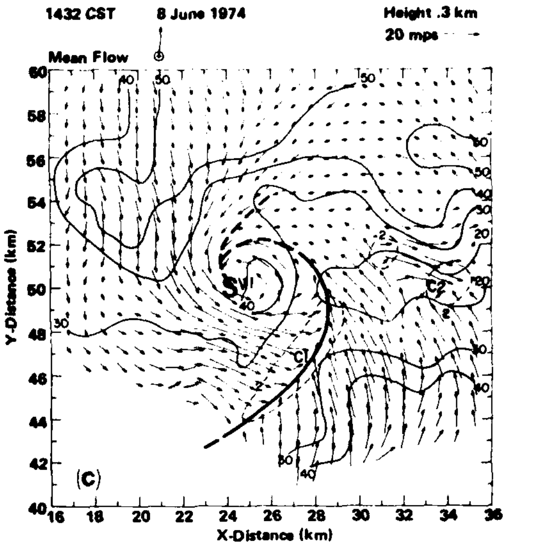

Figure 4(c). Horizontal wind field analysis by Doppler radar of Oklahoma City storm of June 8, 1974

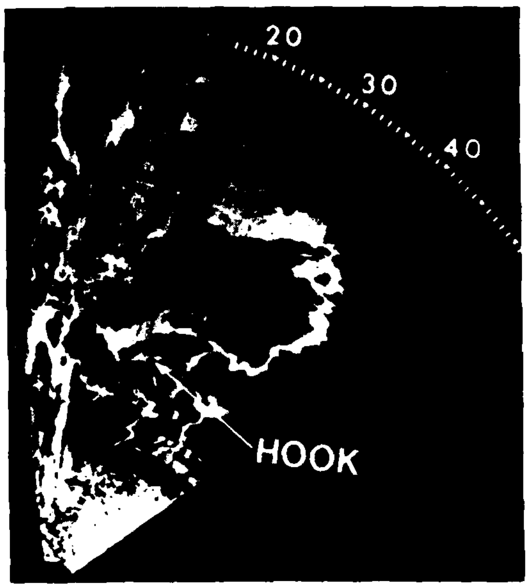

Figure 5. Contoured PPI display of Doppler radar for Oklahoma City storm of June 8, 1974 (1419 C.S.T.)

than non-producing mesocyclonic centers. In a study of 37 mesocyclones, it was found that a tornado did not occur unless it was preceded by the formation of a mesocyclone. The average lead time before tornado occurrence was 36 minutes. The average core diameter of the mesocyclone was found to be approximately 5.7 Km. and its vertical extent 7.8 Km. Mesocyclones which produced tornadoes had smaller horizontal diameters and were taller and rotated faster than non-tornado producing mesocyclones. The tornado vortex is much smaller than the mesoscale system of which it is a part and is very hazardous to aircraft. Some tentative guidelines for defining a tornado vortex signature have been developed. Additional research to characterize the conditions leading to the formation of a tornado is being conducted.

THE THUNDERSTORM GUST FRONT Since 1976, the Federal Aviation Administration has been studying the thunderstorm gust front in detail using instrumented meteorological towers to determine wind and temperatures in the gust front, acoustic echo sounders to determine the depth of the gust front and a ground-based array of atmospheric pressure sensors to determine the speed of propagation of the gust front over the ground. Additionally, aircraft have been used to acquire data by flying through or near thunderstorm gust fronts. Severe wind shear associated with gust fronts has become a major source of concern in aircraft safety during landing and take-off. Wind shear is defined as the local variation of the wind vector, or any of its components, in a given direction. This variation can be a change of wind speed, direction or both with the distance usually measured in the horizontal or vertical direction. Often, gust fronts extend outward from the parent thunderstorm 10-15 Km. (Figure 6).

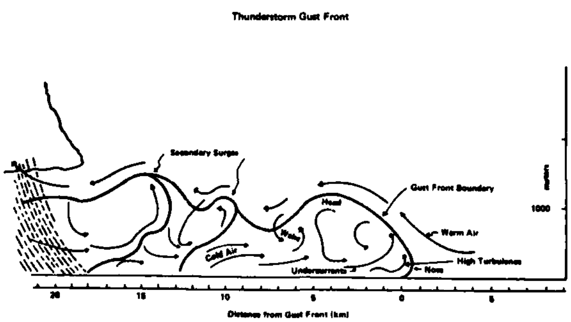

Figure 6. Thunderstorm Gust Front

Thunderstorm gust fronts result from downdrafts of relatively cold dense air produced in storms by evaporative cooling and the weight of precipitation. When this dense downdraft of air (sometimes called a gravity current) collides with the ground, it is forced to spread outward, flowing away from the downdraft center and undercutting the warmer and lighter air outside the storm. The leading edge of this dense air mass is called the gust front. Its passage over a point on the ground is marked by a sharp barometric pressure rise, a temperature drop and a wind shift generally from a South or Southwest direction to West or Northwest with strong gusty winds. An elevated head of dense air is maintained behind the gust front followed by a wake region. This wake region is characterized by turbulence and mixing, expanding in depth with increasing distance behind the gust front. Friction retards the current on the ground so that the leading edge or "nose" may be found some distance above the surface. Dense air moves forward diverging upward in the forward part of the head close behind the front. A large roll cloud may be formed at the top of the head with downward flow behind the head and upward motion in the front part of the head. Updrafts are found ahead of the gust front where the warmer, lighter air is lifted over the head. It is in the immediate vicinity of the head where one can expect to find the most intense wind and wind shear, and therefore the greatest potential aircraft hazard. The maximum speed of the forward flow or undercurrent occurs beneath the downflow at the rear of the head where the forward current is compressed and pushed toward the ground. Because of surface friction, the maximum wind is always some distance above the ground (up to several hundred meters) reaching its lowest height in the core region where the actual wind speed is about 1.5 times the speed of movement of the gust front.

The acoustic echo sounder has shown the internal structure of gust front dynamics in detail making it a valuable tool for wind shear studies. Temperature and wind movements at 6 levels of the 461 m. meteorologically-instrumented KTVY tower at Oklahoma City show the complexity of wind and temperature isopleths through the gust front. Figure 7 shows the depth of a gust front and corresponding wind field isopleths as recorded by the acoustic echo sounder and tower.

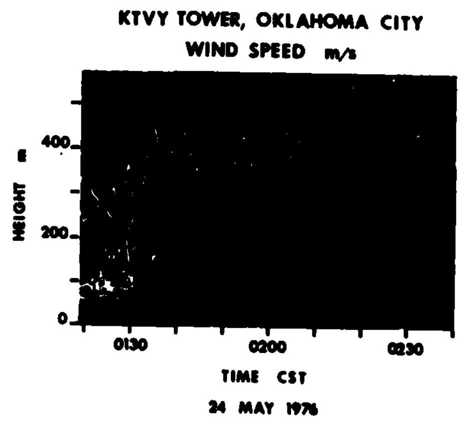

Figure 7. Cross-section of gust front contour from acoustic echo sounder and wind field from KTVY tower.

Some of the results of research on thunderstorm gust fronts has shown that gust frontal slope decreases with diminishing surface drag, that the ratio of the maximum wind height to head depth shows a good consistency and that the multiple surges in the gust front may produce a new head in place of the previous one which has been disrupted by intense mixing.

AIRCRAFT HAZARDS DUE TO GUST FRONTS The aircraft hazards due to gust fronts arise from three wind shear sources:

1. Vertical changes in the horizontal wind causing rapid changes of air speed for an aircraft ascending or descending through a shear layer.
2. Horizontal change of the horizontal wind, causing airspeed to change along a horizontal flight path.
3. Horizontal change of the vertical wind causing vertical displacement of an aircraft flying along a nearly horizontal path.

Wind shear is important to the performance of an aircraft because aircraft lift depends upon the velocity of airflow over its wings. Abrupt or large changes in wind speed can affect lift quickly and drastically so that an aircraft may not be able to respond in time to prevent a sudden drop or rise relative to the approach or take-off paths which can result in an aircraft accident if it occurs sufficiently near the ground (Figure 8).

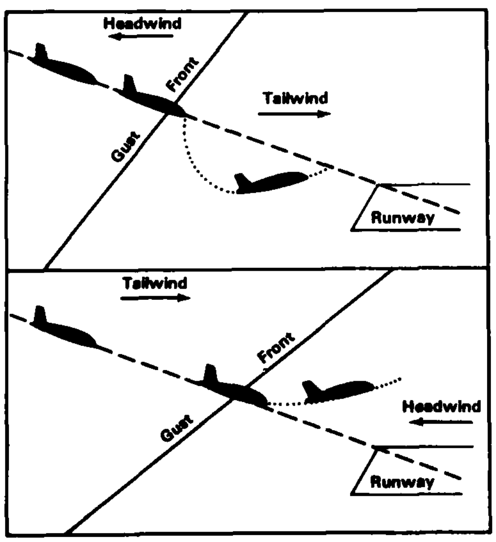

Figure 8. Approach Through Gust Front

Therefore, forewarnings of potentially hazardous wind shear will allow those in command of aircraft to take timely corrective action.

Studies have been conducted with ground-based arrays of pressure sensors at Chicago O'Hare Airport and Dulles International Airport for the detection and tracking of thunderstorm gust fronts in order to test the concept of providing operational warnings to aircraft. It has been found that the speed of movement of the gust front over the ground bears a linear relationship to the maximum vertical wind shear in the front. Doppler radar techniques are also being tested for wind shear detection and measurement of wind fields in thunderstorm outflows.

AIRBORNE SYSTEMS TO AID PILOTS For the past four years, the FAA has been evaluating concepts to assist pilots in coping with low-level wind shear. This has been done in manned simulations as well as in flight tests of experimental avionics. Of those concepts considered as potential candidates for pilot aids, the ground speed versus indicated airspeed appears to have the most merit for alerting pilots to hazardous low-level shears. Recently, the aviation community has had an opportunity to comment upon the above and other wind shear detection concepts by responding to an FAA Advance Notice Of Proposed Rule Making (ANPRM) requiring wind shear detection systems in the National Airspace System. The replies received on the ANPRM are being currently evaluated and a decision on the rule requirement is expected soon.

THUNDERSTORM PREDICTION FOR AIR TRAFFIC CONTROL An effort is underway in the FAA to develop short-range objective forecasts of thunderstorms at air terminals and the surrounding airspace. The Air Route Traffic Control Centers and the terminal air traffic controllers who are in direct contact with the pilot, need sufficient detail in the thunderstorm forecasts in order to plan for aircraft deviations and to give thunderstorm avoidance advisories to pilots. They are therefore interested in the current hazardous conditions caused by thunderstorms and the changes which are likely to occur in these conditions.

Timely very short-range forecasts of thunderstorms with projections of 10 minutes to 2 hours will best suit the needs of the terminal controller. Air traffic flow controllers, on the other hand, are more concerned with the number of aircraft a given air route or terminal can accommodate. One of the best ways of determining with sufficient detail and timeliness the location, movement, and development of thunderstorms which are hazardous to aviation is to process the associated radar echoes. By using the radar reflectivities which have been digitized into discrete intensity levels, automated techniques are being developed to identify, track, and extrapolate the motion and development of local convective thunderstorms at and around terminals.

Among the techniques being investigated are the development of models to isolate, track, and forecast the movement of individual echoes and the development of techniques to track and extrapolate echo centers. Since timeliness is of the essence, emphasis is being placed on techniques which can be readily implemented with locally available facilities.

Forecasts of 10, 20, 30, 60, and 120 minutes into the future are being tested and verification techniques applied. The digitized intensities are integrated over areas of 1 nautical mile and 2 degrees azimuth. Efforts are underway to determine the relationship between severe weather events and parameters derived from digitized weather radar. Short-range forecasts will be presented on the probability of radar echoes of a predetermined intensity at each grid box on the radarscope (Figure 9).

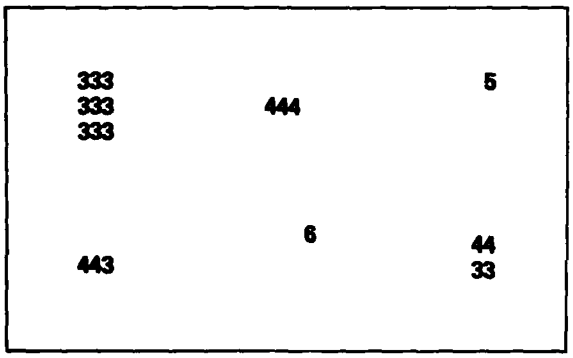

Figure 9. Various thunderstorm echo configurations with intensity threshold of 3 or greater

Archived digitized weather radar data are being used to make and verify forecasts of the probability of radar echoes of predetermined intensities. Predictors which are being used are the vertical integrated liquid water content (VIL), forecasts of echo movement by appropriate tracking models and previous radar observations and trends. Other predictors to be considered are echo tops, tropopause penetrations, synoptic meteorological data and satellite data. Eventual implementation will result in maps of forecast probabilities of echoes of predetermined intensities over the entire forecast grid.

As improvements in Doppler weather radar are developed and tested for operational use, the unique capability of the Doppler to measure wind and wind shear in thunderstorms will also be utilized to improve short-range forecasts of thunderstorms.

CONCLUSIONS Doppler weather radar in conjunction with the WSR-57 digitized radar shows great promise for mitigating thunderstorm-associated flight hazards in the National Airspace System. The capability of the Doppler to measure wind fields inside of thunderstorms will provide timely warning to meteorologists and air traffic controllers of those intense thunderstorms which constitute a flight hazard. As increased knowledge of the thunderstorm and its associated hazards of turbulence, lightning, hail, gust front, wind shear and heavy rain is gained from this research, and as improved forecast techniques for thunderstorm development and movement are developed, the goal of increased air safety and more efficient utilization of the National Airspace System during thunderstorm conditions will be realized.

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AUTOMATION OF AVIATION WEATHER OBSERVATIONS

ERIC MANDEL

ASSOCIATE PROGRAM MANAGER
AVIATION WEATHER BRANCH

BIOGRAPHY

Eric Mandel is an Associate Program Manager in the Aviation Weather Branch, Systems Research and Development Service. He is a meteorologist and a former Naval Aviator. He received a B.S. in General Science from Oregon State University in 1966 and an M.S. in Atmospheric Science from the State University of New York at Albany in 1973.

ABSTRACT

Primary emphasis in the program is placed on automating cloud amount and ceiling, visibility, and present weather elements. Early theoretical work and data collection and analysis led to an operational field test of a system in early 1978 at Newport News, Virginia. This test demonstrated the feasibility of such systems. Further work is now being carried out to improve sensors and algorithms and to design a modular system which can be tailored to the needs of various size airports. Particular emphasis is being placed on development of an improved thunderstorm detector.

BACKGROUND

The need for surface weather observations by aviation is well known. Approximately 1,000 aviation surface weather observations are taken in the United States today by various government and nongovernment agencies. These include the National Weather Service (NWS), the Department of Defense, various airlines and the Federal Aviation Administration (FAA), which takes over 1/3 of the observations at Flight Service Stations and Airport Traffic Control Towers. The FAA has been working with the NWS to develop a capability to completely automate the observation function. This capability is needed to reduce manpower requirements associated with taking observations at manned locations, to provide a capability to continue taking observations at locations where manned facilities are closed and to expand the observation service to new locations where personnel are not available.

Problems exist today due to the lack of weather data at numerous sites. There are over 1,000 airports with approved standard instrument approach procedures but which do not have weather observations taken at the airport. In addition to the general safety problem associated with the lack of good weather information, this lack of data is particularly important to air taxi operators operating under FAR Part 135. Part 135 requires weather observations at airports where these operators land. In addition, a change in the Terminal Instrument Procedures published in 1976 prohibits the use of remote altimeter setting at airports in areas of precipitous terrain. This restriction has led to some approach procedures being disallowed either full or part time due to the lack of a local altimeter setting source.

For the above reasons the FAA's Systems Research and Development Service has had a joint program with the NWS which has led to the development of automated weather observation systems.

TECHNICAL APPROACH

The differing requirements for various airports and available funds will result in implementation of different levels of automated systems at different airports. Large hub airports may require a sophisticated system providing an extensive range of weather parameters while at a small airport only a wind sensor may be justified. For this reason, the approach in this effort has been to develop a modularly related set of automated systems which provide for the implementation of a system tailored for the particular airport in question. For convenience and planning purposes, three levels of automation have been designated.

These are known as the Aviation Automated Weather Observation System (AV-AWOS), the Automated Low-Cost Weather Observation System (ALWOS) and the Wind, Altimeter, Voice Equipment (WAVE) System. Table 1 shows the parameters observed by and components of each system. AV-AWOS can be considered the umbrella system and the work carried out in leading to the development of AV-AWOS applies to the lower level systems as well.

TABLE 1

COMPARISON OF AUTOMATED WEATHER OBSERVATION SYSTEMS

	WAVE	ALWOS	AV-AWOS
ALTIMETER	X	X	X
WIND	X	X	X
TEMPERATURE/DEW POINT		X	X
CLOUD COVER[1]		X	X
VISIBILITY[2]		X	X
THUNDERSTORM DETECTION[3]		O	X
YES/NO PRECIPITATION		O	X
YES/NO FREEZING RAIN		O	X
NONAVIATION PARAMETERS			O
REMARKS		L	X
AUTOMATED VOICE OUTPUT	X	X	X

X - Included in System   O - Optional   L - Included but Limited

[1]ALWOS-1 CHI, AV-AWOS-1 or 3 CHIs.
[2]ALWOS visibility based on one visibility meter - not prevailing visibility. AV-AWOS has three meters is considered equivalent to human prevailing visibility.
[3]ALWOS thunderstorm detection is optional and if implemented will be simple Yes/No. AV-AWOS will include a sophisticated detector.

AV-AWOS

The goal of the AV-AWOS program was to develop a completely automated observation system which would as nearly as possible provide the same information as provided by a human observer. Reaching this goal depended primarily on finding the solution to automatically determine sky condition and visibility as well as present weather and restrictions to vision. It was realized when the program began that it was unrealistic to expect all the information one might desire from an automated system. Therefore. the following basic, operationally important, minimum design parameters were established as initial goals:

- Cloud information to 10,000 feet
- Visibility to 7 miles
- Yes/no hail, precipitation, freezing rain, and thunderstorms

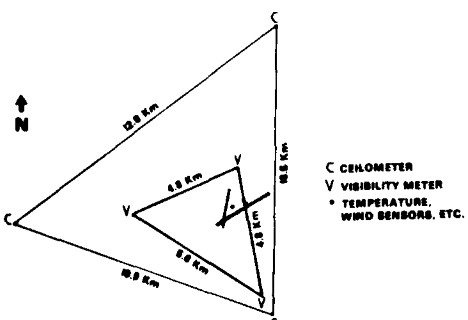
The cloud problem consisted of determining, with a limited number of vertically pointing sensors, the height and amount of coverage (scatter, broken or overcast) of cloud layers. The solution consisted of keeping track of the occurrence or nonoccurrence of ceilometer hits over a period of time and the height of hits. Mathematical techniques modified by meteorological knowledge are used to combine clouds into layers. Layers are then classified as scattered, broken, or overcast based on the percentage of hits assigned to a layer compared to the total number of possible hits.

The visibility problem consisted of determining a value considered equivalent to prevailing visibility using a limited number of visibility sensors. Prevailing visibility is defined as "the greatest visibility equaled or exceeded throughout at least half the horizon circle which need not necessarily be continuous."

There is no known way to scan the horizon circle with an instrument to arrive at an objective value that meets this definition. Visibility conditions generally vary from place to place around an airport. Since the sensors used provide a visibility value representative only of a small area near the sensor, the ideal solution would be to place numerous sensors around the airport in order to sample visibility conditions and obtain an average or prevailing visibility value. In practice, there is a severe limit on the number of sensors available due to the high cost of sensors. The solution used in AV-AWOS is to place the available sensors at selected locations around the airport, obtain a time averaged visibility value from each sensor and use the middle value of these readings as prevailing visibility. The system relies on the natural motion of the atmosphere to move different conditions past the sensors providing the means to sample a large part of the atmosphere near the airport and obtain a representative value of prevailing visibility.

The development model system fabricated for testing consisted of a mini-computer and necessary peripherals, three Rotating Beam Ceilometers (RBCs), three backscatter type visibility sensors, temperature, dew point, wind, pressure, and present weather sensors. The present weather sensors consisted of a sensitive tipping bucket rain gauge for yes/no precipitation, an aircraft type icing detector for yes/no freezing rain, a simple lightning detector for yes/no thunderstorm, and a momentum type hail detector. The initial AV-AWOS tests were conducted at the NWS Research and Development Center near Washington, D. C.'s Dulles airport. The cloud and visibility sensors were installed in triangular configurations around Dulles with the visibility sensors approximatey 1-2 miles from centerfield and the RBCs 3-4 miles from centerfield. The AV-AWOS observations were not used operationally during this period. However, comparisons of the AV-AWOS visibilities and ceilings were made with the NWS weather observers at Dulles. Machine and human observations compared well. One of the goals of the development effort was to determine the minimum acceptable number of cloud and visibility sensors necessary to obtain valid sky condition and visibility information. The results at Dulles indicated that for visibility equivalent to prevailing visibility three sensors are necessary--while in the Dulles type meteorological environment, one cloud sensor provides sky condition essentially as good as three. The number of sensors is important due to the high cost of visibility and cloud height sensors.

Subsequent to the testing at Dulles, a full-scale operational field test was conducted at Patrick Henry International Airport (KPHF), Newport News, Virginia. The reasons for conducting the KPHF test were to gain experience with the system operationally, obtain user reaction and collect data in a meteorological environment different than Dulles in order to gain more information regarding the number of sensors required. The cloud and visibility networks at KPHF were deployed similarly to those at Dulles (see Figure 1). The remaining sensors and the processor were installed on the airport. The AV-AWOS also interfaced with the Runway Visual Range (RVR) system already installed on the airport and automatically accepted and disseminated RVR data.



LOCATION OF AV-AWOS SENSORS IN RELATION TO THE PATRICK HENRY INTERNATIONAL AIRPORT RUNWAY COMPLEX
FIGURE 1

In order to exercise the AV-AWOS operationally, the plan at KPHF was to replace, as often as possible, the manual observations taken by the FSS observers with the AV-AWOS observations. The FSS continued to take observations 24 hours a day as they normally do. To insure safety, the automated observations were monitored by independent NWS observers and the observations compared with those taken by the FSS. If any parameter in the AV-AWOS observations differed from the FSS observation by an amount considered important enough to affect safety, then dissemination of the automated observations was stopped and dissemination of the human observations resumed until the significant differences no longer existed.

The automated observations were disseminated nationwide via the standard teletype circuit and through other normal channels. In addition, the automated observations were disseminated via Cathode Ray Tube (CRT) displays in a number of local facilities, including Norfolk approach control. The AV-AWOS observations were also disseminated via computer automated voice, a subsystem of the AV-AWOS. The computer voice was broadcasted on a VOR voice channel and was available to users by telephone. The CRT displays were updated with a new observation once every 5 minutes while the voice message was updated once each minute.

Figure 2 compares an AV-AWOS observation with a manual observation. The word "AWOS" was used to flag the observation as automated, alerting the user to expect differences from the human observation. The AWOS observation in this example did not report the 15,000 foot overcast due to height limitations of the cloud height indicators. The rain is reported as precipitation (P), while the fog and smoke are not reported. The rest of the report is the same.

HUMAN

PHF 15 SCT M25 BKN 150 OVC 1/2V RFK 132/60/58/1310G25/993/
R04VR10V25 VSBY 1/4V3/4

AV-AWOS

PHF AWOS 15 SCT M25 BKN 1/2V P 132/60/58/1310G25/993/
R04VR10V25 VSBY 1/4V3/4

A Sample of a Possible AV-AWOS Report
Compared with a Human Report
FIGURE 2

Analysis of the Newport News data has shown that automation of sky condition and visibility has been accomplished and that, provided adequate sensors are available, automated weather observation systems are practical (References 1 and 2). The primary problem encountered at Newport News was that the visibility meters provided unrealistically low visibilities under certain conditions. This problem is being addressed by the establishment of a visibility test bed where various visibility devices will be compared with transmissometers and various instrument siting options will be examined. The transmissometer is considered a baseline or standard visibility measuring device. However, it is impractical for use in automatic weather systems at unmanned sites due to the large area required for installation, its relatively high maintenance costs, and because its range is limited to relatively low visibility values.

Another problem is the current lack of an adequate cloud height indicator. It will be noted that at KPHF RBCs were used. Attempts to procure modern laser cloud height indicators that meet operational and eye safety requirements have been unsuccessful to date. While RBCs sufficed for the purposes of the test at KPHF, they are unacceptable for future operational systems for a number of reasons, including high installation and maintenance costs and inability to reach the 10,000 feet desired. At Newport News the RBCs were limited to 7,000 feet. The FAA and NWS are pursuing this vital prerequisite to deployment of automated observation systems.

ALWOS

In June 1977, nine general aviation user groups sent a joint letter to the Secretaries of Transportation and Commerce indicating a need for a means of observing the weather at many more general aviation airports. As a result the ALWOS program was started. While the goal of AV-AWOS was to duplicate the human observer, in so far as possible, the goal of ALWOS was to develop a low-cost system providing the minimum necessary operational information. Consultations between FAA, NWS and general aviation user groups resulted in the parameters shown in Table 2. A developmental model of ALWOS is being fabricated by the NWS and is scheduled for testing at Dulles International Airport beginning in February 1980.

TABLE 2

MINIMUM REQUIREMENTS FOR ALWOS

1. Cloud height and cloud cover

   Measurement to 5,000 feet strongly desired with 3,000 feet the absolute minimum. Measurement to 5,000 feet is minimum requirement in mountainous terrain. Resolution - 100 feet.

2. Visibility

   Zero to five miles. Resolution - one-half mile.

3. Altimeter setting

4. Wind speed and direction

5. Air Temperature

The primary challenge in the ALWOS effort is to restrain costs. Therefore, the number of cloud height and visibility sensors is restricted to one each. Since it is impossible, by definition, to determine prevailing visibility with a single visibility sensor, the visibility value reported by these systems will be somewhat different, and will be, in a sense, runway visibility. Inclusion of other sensors (precipitation, etc.) in the low-cost system will depend on the availability of low cost, reliable sensors and the particular needs of the airport in question. Chances of wide spread deployment of such systems would be enhanced by the development of less expensive cloud height and visibility sensors. Based on current estimates, the visibility and cloud height sensors will account for approximately 60 percent of system costs.

WAVE

There are over 1,000 airports in the United States which have approved instrument approach procedures but no altimeter setting at the airport. At all of these airports where the altimeters setting used at the airport is measured at a location over 5 miles from the end of the runway (remote altimeter setting), the minimums for instrument approaches at the airport are increased by 5 feet for each mile exceeding 5 miles. This raising of minimums for approaches, or penalty, can result in less utilization of the airport during IFR conditions than would be the case if the altimeter measuring equipment were located at the airport. Until recently, the use of remote altimeter setting has been authorized by FAA regardless of the terrain between the runway and the remote altimeter. However, a July 1976 change in Terminal Instrument Procedures (TERPS) has resulted in a restriction in the use of remote altimeter setting where the terrain is considered precipitous. Based on this new decision, a case-by-case review of IFR approaches making use of remote altimeter setting has resulted in FAA disallowing IFR approaches or increasing minimums at some airports. Additionally, there have been some requests for authorization of new approach procedures which have not been approved due to lack of local altimeter setting.

In addition to the altimeter setting problem just discussed, a problem also exists with the nonavailability or inadequacy of wind information at many airports. Some of the over 1,000 airports discussed above as well as others which have no IFR approaches authorized are included in this category. The NTSB has cited wind as the weather factor most often the cause of general aviation accidents.

These problems have resulted in the WAVE effort. A successful 8 month test and demonstration of a WAVE system was completed in September 1979, at Frederick Municipal Airport, Frederick, Maryland. The test system was well received by users operating at Frederick. As with AV-AWOS and ALWOS, the WAVE system includes an automated voice subsystem. The system at Frederick also included an input device with which the airport operator could select a favored runway when the airport was manned. A voice message, updated once each minute, was broadcasted on the Frederick TVOR as follows:

> Frederick, automated weather observed at 1234 Greenwich, wind 180 at 25, Peak Gust 35, altimeter 2999, runway 19 favored.

ENHANCEMENTS

Enhancement work on automated systems is underway in two areas. The first is a device which will be able to detect and classify present weather and obstructions to vision and the second is an improved thunderstorm detector.

The work in present weather and obstructions to vision is being carried out by the NWS. The device being developed is a Laser Weather Identifier. The system analyzes laser light induced signatures of hydrometeors to determine whether it is raining, snowing, whether fog is present, etc. Results to date in this area appear promising.

The FAA is working with a contractor toward development and test of a sophisticated thunderstorm detector. The detector used at Newport News simply indicates the presence of a thunderstorm in the area. The new detector promises to provide distance and direction to the storms as well as direction of movement and intensity. Two systems have been fabricated and will be tested in 1979. One will undergo test in Florida and the other in Norman, Oklahoma, where the National Severe Storms Laboratory will compare the system with their Doppler weather radars.

SUMMARY

Work over the past few years by FAA and NWS has resulted in the successful automation of aviation surface observations. Further work currently underway to refine sensors will, in the near future, result in operationally feasible systems. Ultimately the result will be implementation of a series of modularly related systems which will allow for tailoring of systems on an airport-by-airport basis, depending on the weather and other operational factors. These systems can relieve the work load associated with observing at manned sites and provide the opportunity to promote aviation safety by expanding the observing network to new sites.

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COMPUTER GENERATED VOICE RESPONSE DEVELOPMENT

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BIOGRAPHY

Carey Weigel is a Program Manager in the Flight Information Services Division, SRDS, and is responsible for the development of pilot direct access concepts for the Flight Service Station Automation Program. He received his BSEE from the University of Maryland in 1966 and prior to coming to the FAA, was a Project Engineer for the U. S. Army Limited War Laboratory at Aberdeen Proving Ground where he managed navigation and surveillance systems development. Mr. Weigel's primary role for the past two years has been the development, test and public evaluation of voice response and experimental weather products for pilot preflight and inflight briefing.

ABSTRACT

Rapid access to up-to-date weather products for preflight planning is critical to flying safety. As part of the FAA's Flight Service Station Automation Program, a computer generated voice concept has been developed to assess the feasibility of pilots interacting directly with a computer to obtain available weather and flight data on a timely basis. This paper will describe Voice Response System (VRS) technologies that have been studied, prototyped and evaluated to determine technical and operational characteristics when utilized for FSS applications. Raw weather data shortcomings have been identified and activities to develop new processable weather forecast products have been initiated. A public demonstration of an initial VRS capability was completed utilizing a digitized voice response technique concatenating prerecorded, digitized and stored, vocabulary words and phrases. This capability continues in operation in the Washington, DC, area and brings before pilots for the first time computer generated voice dissemination of weather products. Expanded applications of VRS are anticipated for additional weather and flight products and route-oriented briefings. Future development activities regarding VRS will concentrate on new and improved weather products and capabilities such that higher quality preflight and inflight weather data can be provided General Aviation pilots. A task is also underway to evaluate newly available state-of-the-art digitizing techniques. Implementation of VRS will be accomplished as part of the integrated FSS Automation Program.

Based on the overwhelming pilot acceptance of the VRS in the Washington area, we are in the process of initiating activities which will lead to integration of a VRS capability in the FSS Automation program.

BACKGROUND

Pilot preflight briefing for weather and aeronautical data is an essential part of planning a safe flight. Every year National Transportation Safety Board statistics reveal an alarming percentage of weather related aviation accidents. Many of these types of accidents can be avoided when pilots acquire and take appropriate action regarding pertinent and up-to-date hazardous weather information - before they leave the ground. The concern for rapid access, updating and availability of these often critical weather products, particularly during the pilots preflight planning process, has been a prime reason for the development of the Federal Aviation Administration's (FAA) new concepts of pilot briefing. The substance of this paper will describe our development approach to one of the most promising preflight briefing techniques on the horizon, computer generated voice response.

The FAA is currently initiating a program to automate the Flight Service Stations through the application of high speed data communications and computer processing techniques. The data required will be collected, formatted and edited, distributed and displayed by automatic means. The Flight Service Specialist will be provided with a video display and keyboard to retrieve data in a standard format from the national meteorological and aeronautical data base. These capabilities will greatly enhance the operation of the specialist function. However, in order to meet future demand and provide quality preflight briefings without substantially increasing the FSS staff, a means must be made available such that pilots can completely or partially brief themselves. This aspect of the automation is generally referred to as "direct user access" and employs concepts that enable a pilot to directly communicate with the computer data base and select those products needed to satisfy briefing requirements. These direct user access techniques are vital to the cost effectiveness of the overall automation program.

One of the primary candidates for pilot direct access is computer generated voice dissemination of weather products. The computer generated voice or Voice Response System (VRS) would be located in major population areas and be accessible via the existing telephone network. For the purposes of the FSS development and application, the voice response capability is defined as a system that can automatically, and in a natural sounding voice, read to the pilot information which is digitally assembled and stored in a computer data base.

The FSS has many potential applications for a voice response system since its major is to disseminate numerous types of weather and flight data reports. Currently, some FSSs maintain taped prerecorded messages such as the Transcribed Weather Broadcast (TWEB) for inflight dissemination over a VOR or beacon frequency and the Pilot Automatic Telephone Weather Answering Service (PATWAS) accessed via the telephone network for preflight briefing. These products require substantial manpower in order to generate them and maintain their currency. The VRS, when fully developed, can provide these services cost effectively and automatically. In addition, a new feature allowing pilots to select particular reports for locations across the country can also be made available. Future applications for such services as automatically prepared route briefings and automated flight plan filing with VRS prompting are possible. All that is needed is well-thought-out development, building block implementation and careful integration of user requirements.

The application of voice response to the FSS requirement areas noted above present some very unique challenges to design engineers and, in particular, applications programmers. Voice response systems are available commercially today; however, typical applications are very straight forward, generally limiting user inputs to numeric entries and retrieving/speaking data that is very terse, limited in vocabulary and under very strict control in regard to format and content. Many examples are available. The most familiar is probably the bankteller or salesperson verifying a credit transaction, who enters an account number and receives, automatically, the verbal computer readout of he requested information. Those systems are very effective; however, from a technical standpoint, they are very well bounded having the characteristics noted above and seldom exceeding 100 to 200 words of vocabulary.

PRODUCTS/EXPECTED RESULTS

The purpose of the FAA's development in this area is to determine if VRS is operationally feasible, establish support and source data requirements to drive a VRS capability, evaluate alternative VRS technologies and evolve an implementation strategy and plan such that VRS can operationally be made available to pilots on a widespread, nationwide basis. Specifically, end products will include:

- Operational prototypes of selected VRS technologies.
- Test and evaluation reports verifying operational feasibility and designating needed design parameters.
- National plan for VRS implementation.
- Procurement package of requirements and specifications.

At this time, based on public response to date, we fully anticipate pilot acceptance of the basic concept and are in the process of initiating activities which will lead to integration of a VRS capability in the FSS Automation program.

DEVELOPMENT APPROACH

In the last three years, several parallel development activities have been directed at the application of voice response technology to the pilot direct access function. The general approach has been to learn something about voice response techniques, determine the impact of current weather data formats, etc., on potential VRS applications and try to assess user acceptance and general operational feasibility. To support this approach, three task areas were established:

A. Develop voice response systems-hardware and software.

B. Study weather data characteristics and vocabulary requirements.

C. Define and evaluate operational capabilities, such as features, protocols, formats and content.

A. Voice Response System Development

Computer generated voice response systems typically consist of a vocabulary of words and/or phrases, a data base of information to be spoken and a means of assembling the required vocabulary items in such a manner as to provide coherent responses to the user. Two general categories of voice response technology are currently available: synthetic voice response and digitized or waveform coding. Synthetic systems utilize a set of parameters which describe a basic speech waveform, such as frequency content, to create appropriate utterances. These utterances when programmed together "sound" like a person speaking. The technique is totally artificial. The hardware device that creates the utterances can be best described as an electronic analog of the human vocal system. The digitized or waveform coding systems on the other hand produce a voice output that is based on actual recordings of human speech. The original speech signal is represented by digitally recording its amplitude as a function of time. The digital representation of the word is then stored in the computer for later recall. Various configurations of each of these technologies can be acquired essentially as "off-the-shelf" items; however, the uniqueness of our applications dictated a development effort to tailor the voice response system design specifically to the complex software required for weather data processing. It was decided to build both a synthetic and digitized VRS such that a technical and operational evaluation could be made regarding each respective system for the FSS applications.

Synthetic VRS

A synthetic voice system was developed for the FAA by the MITRE Corporation, METREK Division, at McLean, Virginia, and employs as the basic speech device the VOTRAX ML-1, built by the Voice Interface Division of Federal Screw Works, Inc. The VOTRAX synthesizer utilizes one of the fundamental concepts in speech technology called phonemes as its waveform parameter. A general discussion of a coding scheme based on this parameter provides an example for understanding the general concept of synthetic operation.

Every spoken language consists of a set of fundamental sounds called phonemes. These sounds are strung together forming vowel and consonant sounds in such a manner as to make up the spoken language. For example, the vowel sound "i" as in "bite" is produced by the phonemes "ah" and "ee". Most languages consist of less than 200 phonemes, with the number in common usage ranging from 50 to 60. Slight variations can be given to each phoneme by changing the stress (i.e., angry, calm, or happy) and duration (how long the particular phoneme takes to pronounce). Stress does not vary by much at the phoneme level; limiting the stress to four different values is adequate to cover most speech. Duration for most phonemes is covered by range of 25-100 ms. Using 15 ms steps from 15-240 ms (16 steps) is sufficient to satisfy duration range requirements.[2] Some synthetic systems may include other variations as phoneme modifiers.

A data rate can be determined for this basic encoding method. For example, lets assume each encoded value corresponding to an eventual utterance contains three parameters: the encoded phoneme, its stress and its duration. Since the number of phonemes is less than 200, the phoneme can be encoded as an 8-bit integer. Stress, which can be one of four possible values, is as a 2-bit number. Duration can have one of 16 possible values, thus requiring a 4-bit integer. This method gives a total of 14 bits for each encoded utterance or sample. Since phonemes are typically greater than 25 ms in duration, the number of samples per second will be 40 or less, giving a maximum data rate of 560 bit/s for a synthetic system using phonemes as the encoding parameter.[2]

The synthetic test system configuration assembled for the FAA is shown in Figure 1. Each phoneme command in this system consists of 2 ASCII characters, although only 12 of the 16 available bits are used. These bits contain the information for the basic encoding parameters as the phoneme, amplitude, duration and stress. This particular unit is only capable of uttering approximatey 80 phonemes; however, that appears to be adequate to speak understandably. Typically, there

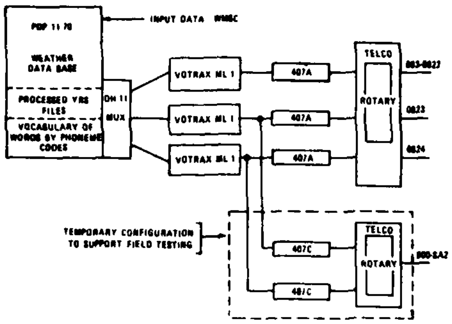

Figure 1 - Synthetic Voice Response System

DIGITIZED VOICE RESPONSE SYSTEM

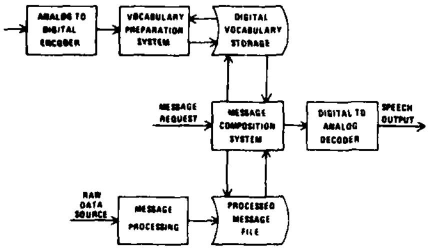

Figure 2

are roughly as many phonemes required to generate a word as there are letters in the word.

For evaluation and demonstration purposes, the VOTRAX system currently delivers up-to-date hourly surface observations, terminal forecasts and forecast winds aloft to calling pilots. This system utilizes vocabulary translation tables to convert data supplied by the Weather Message Switching Center (WMSC) in Kansas City to the character structure required by the VOTRAX units. The computer which accomplishes these tasks is a DEC PDP 11-70 processor. Tests and demonstrations with this system have received favorable results. Pilot ability to understand and copy information spoken by the VOTRAX has been good. The primary drawback for general public applications is the pronounced "classical computer robot voice" that is characteristic of its sound.

Digitized VRS

The general concept of operation for a digitized VRS is shown in Figure 2. A

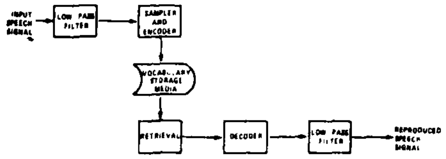

Figure 3 - Digital recorder/reproducer. Speech signal is first filtered to remove high frequency components unnecessary for quality speech reproduction. Cut off frequency of filter is 3KHz. Filtered signal is then sampled at a rate of at least twice cutoff frequency (6KHz) and samples are stored on digital storage medium such as magnetic disc. Speech reproduced by retrieving speech samples and decoding them by applying function which is inverse of the encoder function. Resulting signal is filtered to remove distortion introduced by sampling process, giving reproduction of original signal.

person on a one-time basis, records a vocabulary of words and phrases. These recorded vocabulary items are digitized according to an encoding scheme and entered in the computer's memory. At a later time they are retrieved from memory, strung together with other words as required and converted from digital to analog information for voicing to the pilot. The quality of voice produced by the system is very much a function of the complexity of the digital encoding technique selected.

Digital waveform coding requires that the amplitude of the speech signal be sampled as a function of time. Sampling is accomplished using an analog-digital converter which measures the signal amplitude at regular time intervals and produces a series of binary numbers representing the signal amplitude at each interval. For a sampled waveform, the highest frequency in the waveform which can be reproduced qualitatively is called the Nyquist frequency, which is equal to one-half of the frequency or rate of sampling. Experiments have shown that acceptable quality speech can be reproduced with a speech band-width of 3KHz, thereby, requiring a sampling rate of 6KHz or greater.

The reproduction process is basically the reverse of the recording and encoding process. First, the reproduction process obtains the digital representation of the waveform from the vocabulary storage medium. Retrieved digital samples are converted to an analog waveform by a decoder, such as a digital-to-analog converter. This decoder applies the inverse of the encoder function to each sample to reproduce the original waveform. The basic operations for waveform coding are shown in Figure 3.[1]

Typically, most systems use a sampling rate between 6 and 8KHz; however, the final data rate or bits/second that are required to digitally encode the speech varies greatly between the chosen encoding techniques. Pulse code modulation (PCM) is the simplest and most widely known waveform coding method. Using a conventional analog digital converter, encoded samples are a linear integer representation of the waveform amplitude; if signal amplitude doubles, the corresponding integer sample value doubles. Accuracy of the integer representation in a PCM or waveform coding system depends on a quantity called the step size--the difference in signal amplitude represented by the successive integer sample values. This step size determines the smallest variations in the input signal which will produce a variation in the encoded samples. The smaller the step size, the more accurate the signal reproduction will be. Unfortunately, a small step size results in a large number of bits required to fully describe the sampled signal. This is important since sample size multiplied by sampling rate gives the required data rate for a PCM system.

Although PCM systems are the simplest designs to implement, their data rates are the highest. A sample size of at least 11 bits (data rate of 66K bits/sec when sampling rate is 6KHz) is required to achieve high quality speech reproduction. With this sample size, the distortion introduced by the sampling process is barely preceptible to the listener. Higher distortion levels are tolerable; however, a sample size of less than eight bits (data rate of 48K bits/sec) will introduce more distortion than is acceptable by the majority of listeners.[2]

A decrease in data rates for PCM systems can be obtained through the use of numerous data compression techniques. Some of these techniques dynamically vary the step size, some compare successive sample values for predictable correlation properties. Many techniques combine the various approaches but all have the same purpose--reduce the bit rate required. (It should be noted that the choice of encoding techniques directly affects the size and throughput required for the storage medium). Data rates for the encoded speech signal vary considerably from one technique to the next. The rate depends on the desired signal to voice ratio and, in some cases, the sophistication of the algorithm used to vary the step size. As in most system designs, a trade off always exist. In this case, the trade off is reduction in data rate vs. complexity and cost of step size algorithms.

The digitized voice systems have been developed for the FAA by the Department of Transportation's "Transportation System Center (TSC)" with software contract support from Input/Output Computer Services, Inc. One system is a single channel system for controlled pilot testing; the second system is a multichannel system that can conduct twenty simultaneous pilot briefings with live and current weather data. The multichannel VRS functions as the general waveform coding description presented above; its system configuration is shown in Figure 4. The FSS Development Data Base processor is located at the MITRE Corporation facility in McLean, Virginia, and the VRS subsystem is located at TSC in Cambridge, Massachusetts. It should be noted that these computer systems are the heart of the development activities regarding pilot direct access and as such support much more than just the VRS demonstration.

Pilots interact with the VRS (a DEC 11/34 computer-based system) using 12 key TOUCHTONE® equipped telephones for data entry. Their request for data is transmitted to the FSS Development Data Base which retrieves the required weather data (i.e., the words and phrases spoken for the particular weather report) and sends it back to the VRS. The VRS looks up the digitally encoded speech files corresponding to each of the specified words and phrases in its vocabulary, converts the vocabulary item to its analog (audio) form and routes it to the pilot through his telephone. The VRS can accommodate up to twenty pilots in this fashion.

Current raw weather data is received periodically by the FSS Development Data Base Processor via a 2400 bps synchronous communications line from the Weather Message Switching Center (WMSC) computer at Kansas City. The information is stored in a circular file called KCW. All of the weather data delivered by the VRS has its origin in this file. The raw weather data conversion process uses a dictionary look-up procedure to translate the textual data into binary representations. The binary information represents the position and length parameters that correspond to digitized words and phrases which are stored on the VRS computer's fixed-head disk.

As each weather report or forecast is processed, it is sorted in another file on the FSS Development Data Base disk unit. This file, called the Universal

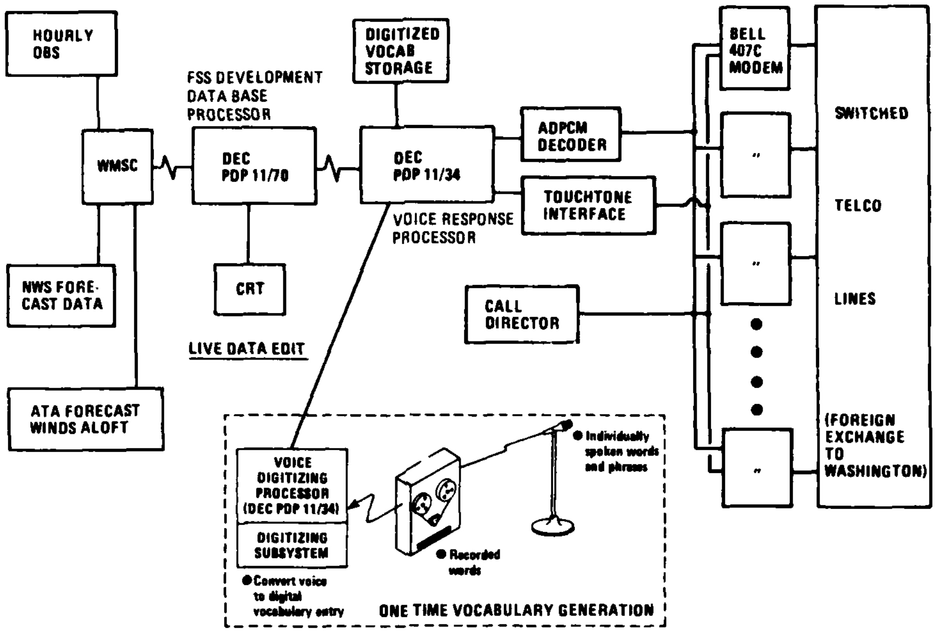

Figure 4 - Multichannel VRS System Configuration

Data File, or UDF for short, contains all of the elements required to perform the processing of the raw weather data into "retrievable" VRS messages.

Approximately 725 words and phrases are contained in the system vocabulary. These items were recorded by a professional radio announcer and then digitized onto the VRS computer's fixed-head disk unit using a process known as Adaptive Differential Pulse Code Modulation (ADPCM). The ADPCM process reduces the normal 11 bit PCM speech sample to 4 bits. Using this technique, one second of speech results in 24000 data bits using a sampling rate of 6KHz. On output, the code words corresponding to speech utterance of a particular weather report or message are decoded and converted from their digitally stored form to their analog representation, thereby, reproducing the original speech sounds.[1]

The speech quality produced by this system is quite good. The sound is natural, pleasing, completely intelligible, and of high quality. However, as with all speech concatentation systems, the speech can be choppy at times, particularly if the text being spoken is awkwardly constructed.

B. Weather Data Characteristics and Vocabulary Requirements

One task that is common to both the synthetic and the digitized systems is the area of message porcessing. Basically, this is the software that is required to look at all the weather data coming into the computer, determine what those messages are saying and generate a list of respective vocabulary items (or phonemes) needed to speak the reports to the pilot. This processing requires a set of rules for the formats, contents, etc., for the raw data and unfortunately is subject to many problem areas regarding the weather data currently available in today's Service A system. Very little standardization in either format or content exists. This standardization is essential in order to accomplish computer processing and a system like the VRS cannot operate without it. Typical anomalies encountered in the raw data are shown in Figure 5. Much of these standardization problems result from the messages being constructed from free text. In the future, these messages must be generated in a computer processable format.

The length of messages also is important for voice response applications from the standpoint of pilot ability to listen and absorb information. On a printer for example, many long messages can be printed and the pilot can visually scan the reports to obtain his required information. The VRS on the other hand would take a very long period of time to read long messages, such as an area forecast, and the listener's ability to assemble in his mind all the elements of information critical to him is doubtful. Therefore, we believe that VRS messages need to be fairly concise. Some testing has been accomplished to verify this consideration.

Another aspect of the data that is critical to VRS applications is the size of the vocabulary needed to speak the messages. We have found that for the implementation of three products, i.e., surface observations, terminal forecasts and winds aloft, approximately 725 words and phrases are required for a national data base assuming most of the location identifiers are spoken in phonetics. The categories of vocabulary items are shown in Figure 6. The required vocabulary would expand to almost 4,000 items if all report types were contained in the system. The size of vocabulary signficantly impacts system cost particularly utilizing the digitized voice concept. At this time, however, because of other constraints mentioned such as size of report, standardization, etc., it does not seem likely that all report types as they currently exist would be made available on the VRS. Presumably newly designed formats and contents of reports will also bring with them a reduction in the number of vocabulary items required.

TYPICAL ANOMALIES ENCOUNTERED IN RAW DATA

- LEGITIMATE WORDS, OVERLOOKED IN VOCABULARY PREPARATION
- MISSPELLED WORDS, INCLUDING WORDS RUN TOGETHER
- NON-STANDARD VARIATIONS IN SPELLING OR ABBREVIATIONS
- ERRONEOUS CHARACTERS WHICH MUST BE DELETED
- NON-UNIQUE EXPANSIONS OR CONTRACTIONS
- TRANSPOSED ENTRIES ON KEYBOARD (UPPER-LOWER CASE)

EXAMPLES

- *AND* IS A LOCATION IDENTIFIER FOR ANDERSON, S.C., AS WELL AS THE CONNECTOR "AND"
- *NE* COULD BE NORTHEAST, NEW ENGLAND, NEBRASKA
- *OCCASIOSIONALLY* – OCNLLY, OCNLY, OCLY
- *ADVISORY* – ADVSY, ADVY, ADZY, ADV

Figure 5

C. Definition and Evaluation of Operational Concept

Pilot use of the VRS has been an area of much study and evaluation. An initial test was conducted at the National Aviation Facilities Experimental Center (NAFEC) in January 1977 to consider various protocols and formats for weather product presentation. Because message processors were considered not feasible for all report types initially, a beginning set of products consisting primarily of hourly surface observations, terminal forecasts and forecast winds aloft were developed. These reports did not consist of enough information to enable the VRS to present a PATWAS or TWEB type of briefing; however, it was determined that these 3 products could effectively provide a pilot with early flight planning information sufficient for a go, no-go to the airport decision. Selection of specific reports necessitated the use of a TOUCHTONE[R] phone rather than a rotary dial phone since the pilot had to enter information into the computer in order to get a response. This capability is referred to as interactive voice response and utilizes the basic three-letter identifiers as an input on the pushbutton keys to specify locations. Numerous briefing formats and TOUCHTONE[R] protocols were studied. Controlled tests with approximately 60 pilots indicated that the concept was feasible, desirable and effective. Those tests also indicated that additional products were desirable; however, such reports like area forecast were too long to be used effectively. A concept of route processing was evaluated resulting in the conclusion that simply retrieving reports along the route was not suitable because of the excessive verbage presented to the pilot. Clearly a new weather product is needed to facilitate VRS route briefing.

The development approach after 1-1/2 years of effort provided the establishment of several VRS test systems with which to gather information on raw

BASIC WORDS (NUMBERS, LETTERS, ETC.)	312
WEATHER DESCRIPTIONS	247
GEOGRAPHIC DESCRIPTORS	35
CONTRACTIONS	85
WEATHER REPORTING STATION NAMES	12
CONTROL PHRASES (HELLO, ENTER, ETC.)	34
	725

Figure 6 - Vocabulary Requirements For Hourly Observations, Terminal Forecast, And Forecast Winds Aloft

weather and flight data reports and to perform controlled testing on operational concepts proposed for VRS. General pilot and FAA operations support began to build after the NAFEC tests and various user organizations were urging the FAA to implement the concept as early as possible in the automation program. As a result of the success and interest at this point, it was decided to publicly demonstrate a limited initial VRS capability under operational conditions in the Washington, D.C., area to assess the pilot reaction to the concept.

VRS PUBLIC DEMONSTRATION

The demonstration utilizing pilots in the Washington, D. C., area brought first exposure of FSS weather data dissemination via a computer-controlled voice response system to the public. The primary purpose of the test was to determine overall pilot acceptance and usability of the concept; i.e., could it satisfy or partially satisfy a pilot's needs and could he use it effectively? Much additional information was planned for acquisition during the demonstration and a subsequent user survey was designed. The results of all the data gathered have been incorporated as appropriate in the overall development and implementation planning of VRS in the automated FSS system.

The multichannel digitized VRS previously described was reconfigured to support the demonstration. Twenty foreign exchange lines from Cambridge, MA, to Washington, DC, were installed to provide access to pilots from the Washingon, DC, local calling area (Figure 7). Three weather products are provided on the system; hourly surface observations, terminal forecasts and forecast winds aloft (Air Transport Association (ATA) Grid Winds--prepared by National Meteorological Center for the airlines). The system is simple to operate, using a prompted format of presentation with the computer asking pilots for required inputs.3 This approach seemed a logical choice for the initial exposure to pilots since it minimizes required pilot knowledge of the VRS operation. The advertised capability of the briefing was for early flight planning and "go-no-go to the airport" decision-making. In all literature released on the system, it was clearly indicated that the VRS did not contain all the weather and flight data available for complete preflight planning and, as such, was not intended to completely replace the specialist briefing. The FAA feels strongly that pilots should obtain all available products when conducting a preflight briefing, including SIGMETs, AIRMETs, NOTAMs, PIREPs, and a general weather synopsis.

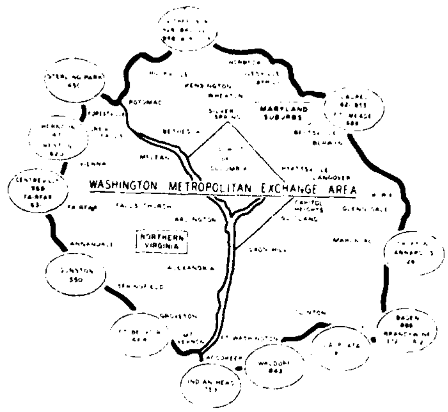

Figure 7 - VRS Toll Free Access Area

In preparation for the demonstration, a special capability for editing data that fails the automatic processors was developed. As noted in a previous discussion on problems with Service A weather data, sometimes a weather report cannot be automatically translated from its raw textual format into a processed "retrievable" format. This condition can rise if the data items are garbled, misspelled, ambiguous, or the corresponding speech utterance is missing from the vocabulary. In that case, the weather report is sent to an edit station where it is manually corrected by a data editor. The corrected report is then filed by the editor for reprocessing by the raw weather data conversion routines. This capability was provided for the demonstration system since at the time the demonstration was planned, there was uncertainty regarding what percent of reports could ultimately pass the automatic processors.

Initial data editing results indicated that although editors were provided, a very low percentage of reports defaulted to the edit position. It was projected that the message processors, as developed, were sufficient to support a three-product VRS with no editing services needed. In such a configuration, those messages which failed the processors could simply be voiced as "not available". The system was made available to pilots 7 days a week, 14 hours per day (limited only by the requirement for editors). The system went into operation on April 15, 1978, and remained in an evaluation status through September 30, 1979.

The VRS system at TSC is shown with operator in Figure 8.

Figure 8 - VRS Test System at TSC

The results of the public VRS evaluation have constituted an overwhelming enthusiastic endorsement of the concept by pilots. Pilots indicated in the survey results that half of the time the VRS, with limited products, satisfied their needs for early flight planning information and when they did call the specialist for additional data, 80% of the pilots indicated the time they spent on the phone with the specialist was reduced by 50%. A total of 93% of the survey respondents indicated they felt that the VRS was suitable for widespread public use as is or with minor changes. In addition to the excellent survey response, many letters and phone calls have been received in support of the concept. The report identified in reference No. 4 contains all analysis and conclusions regarding the evaluation of VRS in Washington, D.C.

Despite the estimate that less than half of the pilots in the area have touchtone telephones, pilot calls to the system have been substantial. The number of callers varies considerably based on prevailing and forecasted weather conditions; however, an average of 400-500 calls are received daily. Typical comments received generally indicate pilot interest in more products being made available, particularly synopsis, weather warnings and NOTAMS.

As a result of continued high pilot utilization the operational availability of the system was extended. In April 1979, the VRS front end unit was moved to the MITRE computer facility in McLean, Virginia, where operation will be continued indefinitely on an expanded basis of 7 days a week, 24 hours per day. The system will be utilized as an operational test bed on which additional weather products and possibly automated flight plan filing techniques can be evaluated.

An additional evaluation to determine the impact of a limited capability VRS on FSS operations is planned to begin in Columbus, Ohio, in November 1979. Information regarding the impact of VRS on the FSS facility, combined with the pilot acceptance data already amassed in Washington, DC, will enable the FAA to properly assess the total feasibility of the concept.

FUTURE DEVELOPMENT AND APPLICATIONS

Earlier in the text, numerous problems, primarily in the raw weather data, were noted. These problem areas are the focal point of future development in VRS. In order for more products to be spoken and conventional PATWAS/TWEB messages to be VRS-generated, raw reports will need to be standardized in some type of computer processable format. Eventually, it would be desirable to have the capability of accepting a route request from a pilot, along with some parameters he considers critical to his qualifications and type of aircraft, and be able to read back for the pilot a synopsis of key weather information along his route of flight. Currently, a joint FAA/NWS program is underway to develop and evaluate candidate data structures which could provide forecasts data and possibly some observed data in such a manner. (See paper entitled "Automated Route Forecasts").

Additional development is planned to accommodate new weather report types and some flight data reports such as NOTAMs and PIREPs on the VRS. Last spring, NWS introduced Convective SIGMETs and began issuing weather warnings by state. Software work is nearly completed such that these reports can be processed and will be available in the near future. Some changes and additions to the existing system will also be developed based on the analysis of the public demonstration results. A combination short and prompted format is needed and will be considered for implementation. Development will also continue using the VRS prompting for interactive touchtone flight plan filing experiments.

As follow-on work directed at VRS implementation progresses, it appears that rapid changes in technology are occuring in the voice response field. In particular, Linear Predictive Coding (LPC) techniques hold the promise of good quality voice production at low costs. To investigate the feasibility of using LPC for FSS applications, an experimental LPC capability using an SPS-21 array processor is currently being assembled in our computer facility at MITRE. Testing of that system using FSS weather products is anticipated to begin in FY-80. Additional information will be available on the LPC work as that task evolves.

Summary

Development of VRS over the past years has progressed very well. Two technology prototypes are operating reliably and are available for evaluation and demonstration. Preliminary results have indicated that from an operational feasibility standpoint, the digitized VRS is preferable to the synthetic approach primarily because of the superior voice quality. Cost analysis for the two systems indicates they are reasonably cost comparable for an installation that would service a substantial number of users (20-30 channels). An analysis of LPC and a prototype system will be evaluated during the coming months to assess its applicability to VRS. At this time we anticipate that the functional use of the system will be relatively independent from the VRS technology selected.

NWS source data (raw weather text) problems have been defined and activities to provide future solutions to these problems as well as create completely new weather products are underway. A continued public demonstration is successfully in progress and pilot support for the concept is building.

In general, applications for VRS are unlimited. Within the foreseeable future in the FAA, VRS can be expanded to provide automatic message generation for FSS radio outlets, terminal information systems, nontower dissemination systems, and automatic weather observations. Other applications undoubtedly will evolve. Outside the FAA, the public demonstration has opened up many possibilities. Numerous business, agencies and technical companies have called the FAA for information on the VRS because they feel the voice quality is excellent and has potential applications in their business. Up to the start of the demonstration, VRS has carried a stigma regarding its use for the general public--always a concern that the voice quality would not be acceptable to nontechnical persons. We believe our VRS development has put that concern to rest.

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AUTOMATED ROUTE FORECASTS (ARF)

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BIOGRAPHY

Carey Weigel is a Program Manager in the Flight Information Services Division, SRDS, and is responsible for the development of pilot direct access concepts for the Flight Service Station Automation Program. He received his BSEE from the University of Maryland in 1966 and prior to coming to the FAA, was a Project Engineer for the U. S. Army Limited War Laboratory at Aberdeen Proving Ground where he managed navigation and surveillance systems development. Mr. Weigel's primary role for the past two years has been the development, test and public evaluation of voice response and experimental weather products for pilot preflight and inflight briefing.

Abstract

Computer processable weather forecast data is essential to support automated pilot briefing concepts using a computer-generated Voice Response System (VRS).

Today, most weather forecast data is generated by the National Weather Service in free text, nonstructured messages. In this current form, such forecast data cannot be automatically processed and spoken by VRS devices. The Federal Aviation Administration in conjunction with the National Weather Service has jointly initiated an experimental program to determine the feasibility of a new grid structure technique of forecasting which can provide a computer processable data base for speaking. The concept is called Automated Route Forecast (ARF) and has the potential for enabling automatic voice systems to provide complete route briefing information. This paper describes the ARF concept, establishes the objectives of the program and highlights some of the problem areas to be resolved and tested. ARF concept analysis and software design are being accomplished under contract to MITRE Metrek, McLean, Virginia.

Background

The primary concept under consideration to automatically provide flight services to users without the intervention of a specialist is pilot direct access. Using this technique, the pilot can directly access a computer of weather and flight data and retrieve for himself required products to obtain a preflight, or, in the future, an inflight briefing.

Initial capabilities associated with this concept have been developed, extensively evaluated, and have been shown to be both effective and efficient.

As a result of pilot testing, product requirements for such an automated system have been proposed. For some applications, such as early flight planning, limited selected products can suffice in providing the pilot all he needs to know to determine whether he wants to go to the airport. However, for complete preflight briefing, the automatic system needs to provide a capability for pilots to obtain a route briefing in some manner such as to be concise, and yet complete, including all the appropriate data critical to his flight.

Initial development and test of the *direct user access concept* concentrated on pilot access via terminal devices. Using this technique, pilots were able to retrieve selected products or request a complete route briefing containing all data available from the Kansas City Weather Message Switching Center. Using these terminals, route briefings were possible but cumbersome. The briefing was assembled by retrieving and displaying all reports applicable from a 50-mile corridor along the route of flight. The quantity of data presented to the user was voluminous. However, since the data was visually presented, rapid scanning and filtering was accomplished by the pilot. Despite the undesirable nature of the data, route briefing via terminals could be reasonably accomplished.

The introduction of computer-generated voice response system (VRS) technology again surfaced difficulties with the data formats currently in use. Tests were intiated to determine the various types of VRS briefings that could be provided from an operational aspect and an analysis was made to determine how much of the existing raw weather data could be readily processed and spoken by the system.

From an operational aspect, it was determined that selected products spoken by voice was a viable concept. Route briefings, however, where many independent weather reporting products were retrieved along the route of flight, resulted in an extremely lengthy and redundant dissertation to the pilot. Test subjects were not able to absorb all the text nor filter out the essentials pertinent to their flight.

An analysis of incoming raw weather data from a processing standpoint indicated a very clear need for report standardization and if route briefings were to be required, the need for major changes was evident. The greatest problems occurred in clear-text messages such as TWEB Routes (TRs), AIRMETS (WAs), and Area Forecasts (FAs). In generating these messages, NWS forcasters have considerable freedom in the phraseology they may use to describe weather phenomena. Some of the variations encountered would include vocabularies, abbreviations, ordering of words and phrases, and the order in which phenomena are described. Some human errors (slashes misplaced, spaces omitted, misspelling, etc.) might also be present. Intelligible VRS output of such clear text requires *consideration of sentence structure*, emphases, intonation, pauses, etc.; not merely having a complete stored vocabulary of words and concatenating them as ordered in the source data. The errors, variations, and permutations encountered in current clear text data makes development of computer programs to reliably process them difficult.

In order to solve both the operational and processing problems noted in the source weather data, a joint effort was considered necessary between the National Weather Service (NWS) and the FAA. Mutual interest existed since NWS was considering automated means to disseminate the many public forecast outlets they man on a costly basis and FAA solidly established voice response as a primary means of offloading excess specialist work load. Together, the two agencies agreed to participate in a program to experimentally develop a new concept for structuring forecast weather data. That concept has been designated the "Aviation Route Forecast (ARF)".

Products/Expected Results

The purpose of developing the ARF concept is to determine if ARF is operationally and technically feasible. These areas will be evaluated both from the NWS forecaster aspect of inputing and updating ARF data and also from the FAA aspect of retrieving and briefing data to the pilot. Emphasis will be placed on evaluating how well a pilot briefed by ARF products can grasp the weather picture intended by the forecaster. Specific end products will include:

- Prototype forecaster input work station

- Prototype ARF retrieval software to deliver complete pilot briefings for evaluation/ demonstration.

- Test and evaluation reports describing the operational feasibilit results.

- Complete documentation on the ARF structure and software design.

Based on preliminary software development, we have judged the concept of ARF to be feasible. Development is proceeding based on that initial decision.

Development Approach

Three primary aspects of ARF have dominated the development approach; Definition of ARF data, Development of forecaster input technques, and the development of ARF retrieval/synthesis. Once these areas have been accomplished, evaluation to establish feasibility can be initiated.

Prior to the start of this activity, the National Weather Service began circulating a strawman document of ARF formats and proposals through various levels of NWS headquarters and field offices. The resultant proposed data structure described below has benefited from the consolidated ideas of many forecasters across the country.

Description of ARF Data

The objective of forecasting in the ARF format is to eliminate the abstractions of clear-text messages and provide measureable, unique, quantified area-type data for general use. The ARF data base divides the entire country into a grid and requires the forecaster to predict specific variables in a numerically coded format for each grid cell. The grid chosen by NWS for use in ARF is the same grid utilized for the Manually Digitized Radar (MDR) data currently in use. This grid conveniently breaks up the geography into homogeneous meteorological areas, each approximately 22 miles square. Its use facilitates the advantage of being able to overlay radar information directly onto the forecasted ARF data.

ARF contains separate forecast data for 0-2 hours, 2-4 hours and 4-8 hours from issuance. Normal updating would take place every 4 hours. As a result of the preliminary coordination between NWS, their regions and the FAA, the following 14 weather parameters were established for input at each of the grid cells:

1. Cloud cover amount
2. Range of cloud bases (above ground level or mean sea level)
3. Remarks pertaining to bases
4. Range of cloud tops
5. Remarks pertaining to tops
6. Inflight visibility
7. Inflight weather
8. Convective activity
9. Freezing level
10. Icing (in clouds above freezing level)
11. Type icing
12. Turbulence
13. Type turbulence
14. Height turbulence encountered

The range and meaning of the values assigned to these parameters in the ARF data design are contained in reference 1. A sample of the forecaster value selections for Cloud Cover Amount is shown in Figure 1.

CLOUD COVER AMOUNT	VALUES	
Clear	0	Sky conditions clear
Scattered	1	Scattered bases
Scattered to Broken	3	Scattered-broken bases
Broken	3	Broken bases
Broken-Overcast	4	Broken-overcast bases
Overcast	5	Overcast bases
Partial Obscuration	6	Sky partially obscured
Total Obscuration	7	Sky obscured

FIGURE 1 FORECASTER VALUE SELECTIONS FOR CLOUD COVER AMOUNT

Each series of ARF arrays for the 0-2, 2-4 and 4-8 hour forecast periods would be produced every four hours and would be valid for the next eight hours. The old data would be automatically removed from the system every two hours. When the forecaster prepares a new ARF forecast, he essentially updates the latest existing forecast, modifying required parameters to satisfy the current prognostic situation or change the time group and period and use it as the 0-2 hour forecast. Figure 2 shows an array of ARF data for one time period of a 22 square mile grid cell.

Intrinsically the ARF concept allows the forecasters to easily amend or modify individual parameters as they change within a forecast period. Currently, a forecaster would have to rewrite the entire forecast. This feature should enable forecasters to keep the forecast more timely and consistent with what is actually being observed.

It has not been determined at this time how many NWS offices would generate ARF data if implemented. Assuming, however, that a number of locations would be involved, techniques must be developed to assure consistency of ARF parameters at the office boundaries. System design should enable the data base processor to check for boundary conditions and either resolve or alert the appropriate forecasters of the problem.

With forecast information stored on the data base in the ARF format, one additional feature particularly useful for flight service application is available. Computer-generated graphics would be developed for each of the forecast variables, i.e., a four-hour prognosis of cloud cover conditions, bases, tops, turbulence, etc., across the country, or over the forecast office or regional area of responsibility. These graphics could satisfy requirements of both the FAA and the WSFO regions for continuously updated low-level significant weather prognoses and forecast depictions.

Forecaster Data Input

A key aspect of ARF that needs to be evaluated is the operational feasibility of the NWS forecaster inputting all the required data for ARF. Within the boundaries of one of the 9 area forecast WSFO's, typically 400-500 grid squares are likely to exist with a requirement for up-to-14 parameters of data to be entered for each grid for each of three-time periods. Therefore, in the order of 20,000 elements of data conceivably could need to be entered into the system every four hours just for scheduled forecasts alone. It is obvious that manual numerical entry of such a quantity of data would not be feasible, therefore, a graphics entry capability is being developed that will allow the forecaster to draw contours associated with individual variables. When all contours for the selected variable have been entered on the graphics device, the computer will automatically process the data and enter the proper numerical value into the appropriate grid cells. The operation then proceeds to enter the next parameter, etc.

During this development effort, the prototype forecaster workstation graphical techniques will be developed to minimize the work load associated with entering the grid data. However, due to limitation of resources, the prototype will not represent the optimum graphics entry capability eventually needed by a forecaster. Some study and analysis will be done to identify the additional considerations needed prior to operational implementation of the ARF concept. This analysis will be documented in a workstation design report.

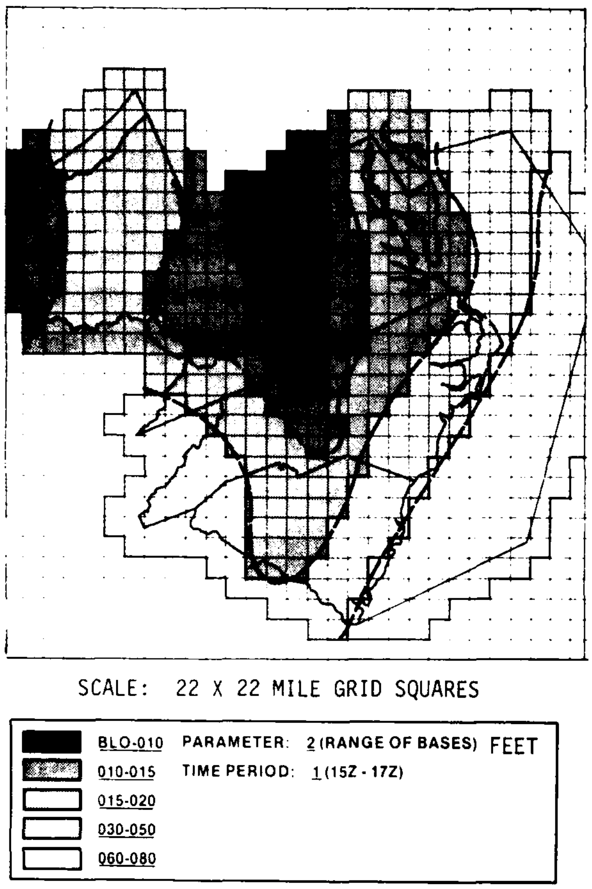
Basic computer programs for initial creation of the data base files, input of an entire ARF data set and associated update/modification/editing functions are currently under development. For this effort, an initial set of static data, compiled by NWS, will provide the analytical guidance for the development of algorithms to shorten and simplify the data input and provide maximum flexibility for data maintenance. Contour digitizing software will be developed to allow multi-cell irregular areas of common entry value to be drawn by the forecaster with the computer identifying the circumscribed cells and writing the values to the relevant data base records. Special functions will be available to correct errors, set the remainder of a region to a value, etc. For data base update, the previous data will be displayable on the map background, to allow determination of the minimum changes needed to effect the update.

A sample of a forecaster entry at his workstation for parameter 2, "Range of Bases" is shown in Figure 2. It should be noted that once the contour has been established, the forecaster designates to the computer the assigned value for each side of the contour. All data for a given parameter can be entered at one time. The forecaster starts anew for the next parameter. The example shown is for actual forecast data assembled by NWS for the Washington Area Forecast area.

Once basic feasibility can be demonstrated, some development effort will be directed at refining the input process from the standpoint of value checking and boundary coordination. It is anticipated that effective algorithms can be designed to minimize erroneous or inconsistent data in these areas.

ARF Retrieval/Synthesis

The heart of the ARF concept is its potential to enable a computer to retrieve forecast data along a route of flight requested by a pilot, and present back to the pilot a summary of all the information pertinent to his flight. This requires development of



FORECASTER ENTERED CONTOURS AND VALUES FOR PARAMETER 2 "RANGE OF BASES"

FIGURE 2

algorithms for synthesis of multi-cell data into concise, meaningful output for each pilot briefing requirement. The unknown is the volume and homogeneity of the ARF data strings that will be retrieved for typical routes. If long and constantly varying in value, the data may be difficult to summarize concisely while maintaining accuracy.

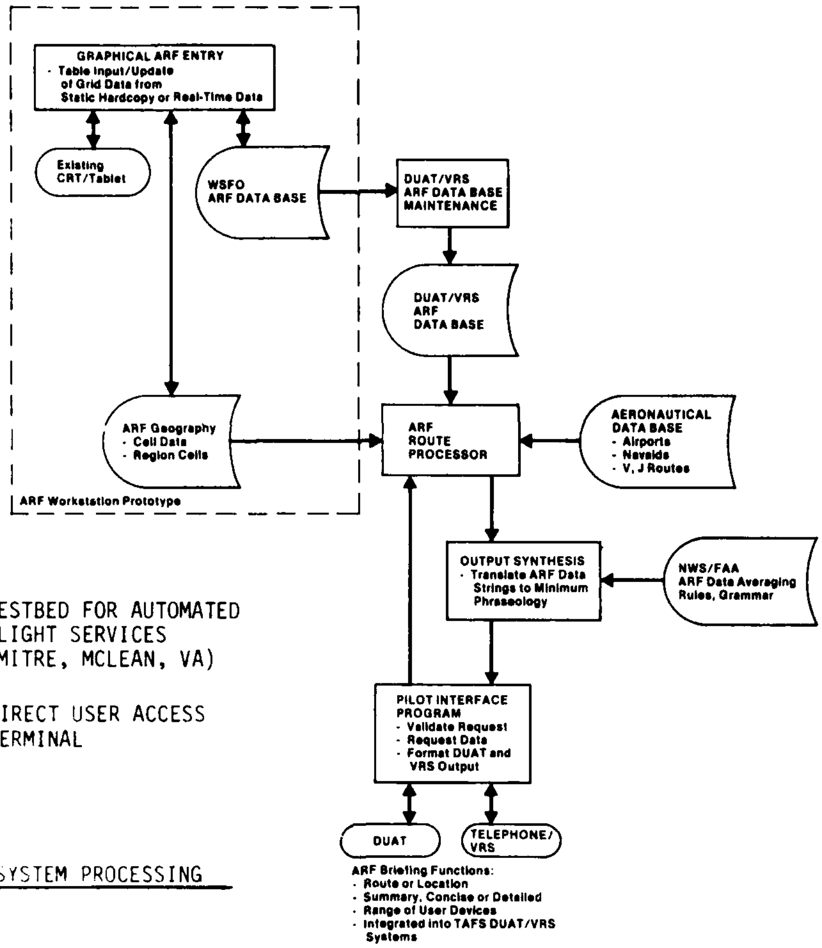
The development approach was to first evaluate data strings taken by hand from the static set of data provided by NWS and determine the magnitude of the problems encountered. This was accomplished early in the project with favorable results indicating that the anticipated processing required would be reasonable. A working group was formed between FAA, NWS and MITRE Metrek personnel to evolve a first-cut set of data averaging rules and a set of appropriate read-back phrases to describe the forecast phenomena to the pilot. Although an initial set of rules was established, an iterative process is expected in order to adequately address the many variations and conditions which appear in the data. The relationship of a selected route of flight on any particular set of data also has a large impact on the definition of the synthesizing rules. For example, if a route of flight parallels a front but the actual abrupt change in data does not occur within the grid cells in the corridor, some special consideration needs to be made to alert the pilot that such a condition exists even though the normal retrieval of the grid squares would not reveal the changes.

The data base design for retrieval/synthesis will be tailored to facilitate efficiency for retrieval operations. Trade offs will be analyzed with regard to updating the files, optimum host throughput, and response time minimization. The design will provide safety features to assure a pilot user does not access an incomplete data file in the midst of an update. Special design considerations will be made to enable improvements to the data base design at a latter time without impacting retrievel processing. A block diagram of planned ARF system processing is shown in Figure 3.

Grid Retrieval Along the Route

When a route is indicated by a pilot, the first function required by the system is the retrieval of the appropriate grid cells along the route such that the pertinent data can be assembled and processed. In previous development of direct user access programs, route processors were designed to retrieve all weather reporting points that had a latitude-longitude falling within the route corridor. For the ARF grid, the same basic route processor has been used, however, the centroids of respective cells have been computed and projected on to the route of flight. The corridor width establishes the criteria for selecting which grid cells are retrieved. Cell retrieval using this technique can result in a somewhat irregular distribution of data blocks. Further analysis will be made during concept refinement when feasibility has been established to determine if a better approach to retrieving grid cells is needed.

Having determined the ARF cells pertinent to a route, additional code will retrieve the relevant cell data by calls to the data base access routines. The retrieved data will be



NOTE:

TAFS - TESTBED FOR AUTOMATED FLIGHT SERVICES (MITRE, MCLEAN, VA)

DUAT - DIRECT USER ACCESS TERMINAL

FIGURE 3 ARF SYSTEM PROCESSING

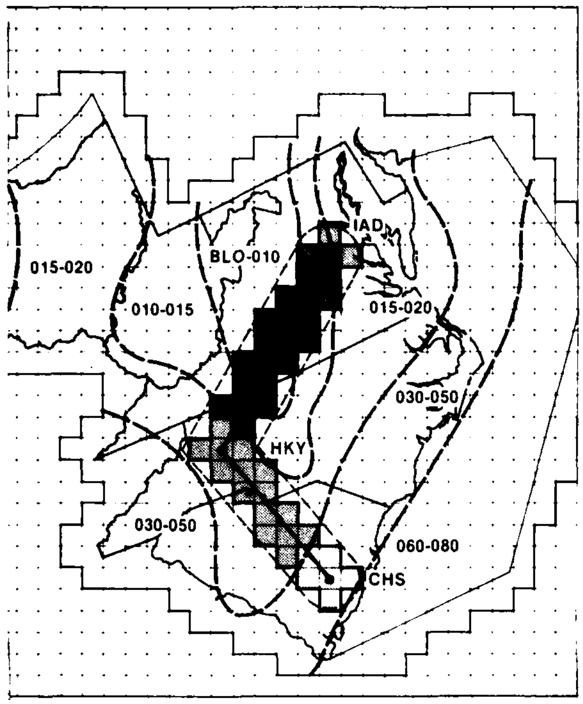
passed as strings to the output synthesis software for processing. It should be noted that the ARF concept is expected to be applicable to both point and area retrieval. Algorithms to retrieve the data cells for these applications have not yet been accomplished but are not anticipated to be difficult.

Output Synthesis

Complete and concise summarization of the data along the route is essential to the viability of the concept. It has been to date the most difficult area to design and has involved much support from NWS/FAA and MITRE in determining an appropriate set of synthesis rules. At the present time, the ARF software basically considers one parameter at a time for processing. This string of values is examined according to the rules established and an appropriate string of output statements is provided. These are then set aside while the next parameter is examined. With respect to the planned flight time profile, consideration must be given to the 0-2, 2-4 and 4-8 hour data time boundaries.

Speaking the output data to the pilot is a task where easy experimentation and pilot testing can be accomplished. Standard phrases will be used but again, the ability of the programs to smooth the data yet maintain necessary information is critical. Expression of the location of events along the route has been to date a subject of uncertainty. Currently, the initial software interpolates events to mileposts along the route legs (either positive or negative correlating to before or after a location). This technique is adequate for initial testing but may not be suitable for implementation. Another option would be reference of events by VOR fix-radials. Various techniques will be evaluated.

Figure 4 shows a route from IAD to HKY to CHS superimposed on the Washington Area Forecast area. The values shown on this figure are for the "bases" parameter and represent a significant weather day. The appropriate grid



SCALE: 22 X 22 MILE GRID SQUARES

Possible Parameter 2 VRS Output for IAD-HKY-CHS Route:

"...**Bases:** 1500 to 2000 at IAD;
Frequently below 1000 through HKY;
1500 to 2000 through CHS Minus 50;
3000 to 5000 through CHS..."

ARF SYNTHESIS OF PARAMETER 2, RANGE OF CLOUD BASE FOR PILOT ROUTE IAD-HKY-CH5

FIGURE 4

cells retrieved for the route corridor are shaded in relationship to the parameter value. This particular parameter with the data as shown works out very nicely, and, with minimal ARF experience by the pilot, is readily understandable.

Pilot testing of the experimental outputs is planned for every phase. Feedback from the testing will be used to appropriately tailor and improve ARF system performance.

Summary

Direct access briefing, in particular VRS, has operationally proven to be an effective means of delivering weather data to pilots. ARF development is critical in order that complete services, i.e., full route briefing, can be realized. The development program currently underway is designed to prove the feasibility of forecaster input and retrieval/synthesis for use with the VRS. Initial demonstrations using canned data generated by NWS have shown promising results. A forecaster input workstation is being developed and an initial set of retrieval/synthesis rules have been assembled. A working prototype system with forecaster input of live data and pilot evaluation of route briefings is anticipated to begin in the second quarter FY 80. Subsequent testing for concept refinements and planning/analysis regarding implementation considerations will follow.

The ARF concept is somewhat revolutionary within the NWS structure of doing business. The format, however, was basically conceived by them and has included the thoughts of many experienced persons within its design. The FAA and NWS have a common need for such a product - automated delivery of weather data to the public. ARF has the potential to enable complete automation of such weather forecast data, not only for aviation weather but for all applications from farm, through marine, to specialized public services or housewife inquiries. Excellent technical work is underway at MITRE Metrek and with continued aggressive and enthusiastic support from NWS, a unique concept that could greatly impact the quality of aviation weather will be available for test by early fall.

Acknowledgement

The author wishes to acknowledge the continued support of the National Weather Service and in particular Mr. E. Gross of the Aviation Weather Branch, whose personal dedication to the automation of aviation weather products has enabled the ARF concept to become a reality. Special appreciation is also extended to the MITRE Corporation, Metrek Division staff, directed by Mr. Tom Mitchell, which has accomplished an outstanding technical effort in the past year in the formulation of a technical approach and computer software development to establish ARF feasibility.

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2. Gross, E. M., et al., (Sept 77) Recommendations for Reorganizing the Domestic Aviation Forecast Program, National Weather Service

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FAA REMOTE TERMINAL SYSTEM FREQUENCY ASSIGNMENT MODEL

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BIOGRAPHY

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BIOGRAPHY

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ABSTRACT

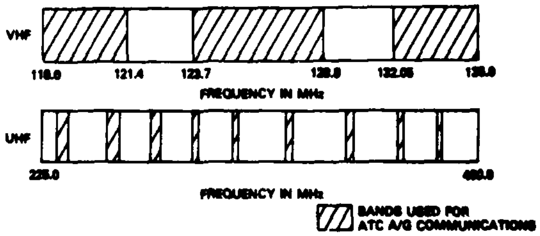
A system of interactive analysis was developed for the Federal Aviation Administration (FAA) to provide automated, quick-response capabilities for use by FAA in solving frequency management problems.

This paper describes the frequency assignment model that was developed as part of the FAA's interactive system. The model is used to make VHF (118-136 MHz) Air Traffic Control (ATC) frequency assignments, and the criteria used, and examples of the operation of the model, are discussed herein.

BACKGROUND

Direct voice communication between pilots and air traffic controllers is a vital link in the operation of the National Airspace System (NAS) by the FAA. To provide air traffic control communications, the FAA makes use of approximately 12.5 MHz of spectrum in the 118-136 MHz frequency (VHF) band to control civil aircraft, and approximately 40 MHz in the 225-400 MHz (UHF) band to control military aircraft (see Figure #1). With these frequency resources, the FAA must accommodate the need for approximately 3000 discrete communications channels. One channel usually consists of one VHF frequency and one UHF frequency, in order to provide control to both types of aircraft at once.

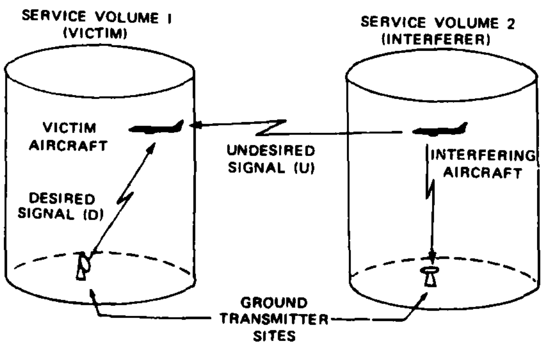
FIGURE #1
SPECTRUM USED FOR ATC A/G COMMUNICATIONS



Models are those specified in the FAA VHF/UHF Frequency Assignment Handbook.[1] This Handbook was derived from international standards and practices,[2] FAA research and development, and actual experience in frequency assignment. Some situations, such as 25/50 KHz interleaving, required that new criteria be developed. The intent of this section of the paper is to describe the most critical interference interaction analyzed by the VHF model, introduce the standard FAA criteria, and discuss those situations for which new criteria were required.

Of the potential cochannel interference interactions analyzed by the model, only the most critical interaction is discussed in this paper. This case is shown geographically in Figure 2.

FIGURE #2
INTERSITE INTERFERENCE INTERACTION

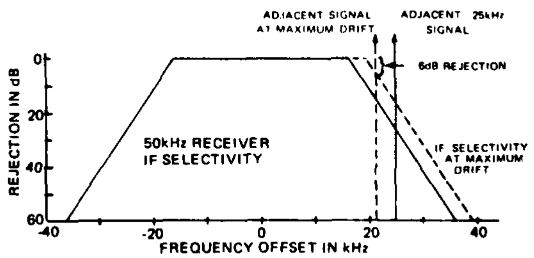


To provide adequate performance, the desired signal (D) at the victim aircraft in service volume 1 must be at least 14 dB greater than the undesired signal (U) from an interfering aircraft in service volume 2. The 14 dB D/U signal ratio must also be realized when the roles of the victim aircraft and interfering aircraft are reversed and for every combination of assignments served by the same frequency.

An assignment must perform as well in the presence of an adjacent channel signal as it does in the present of a cochannel signal. The IF selectivity of an airborne receiver designed for 50-KHz operation is assumed to provide at least 60 dB of attenuation to a signal offset by 50-KHz. An airborne receiver designed for 25-KHz operation is assumed to provide at least 60 dB of attenuation to a signal offset by 25 KHz. With this amount of rejection by the receiver of the interfering adjacent signal, a -46 dB (14 dB-60 dB) D/U signal ratio will achieve performance equivalent to the 14 dB D/U signal ratio specified for cochannel assignments. This would allow adjacent-channel assignments in adjoining service volumes. Even though the desired-to-undesired signal protection is achieved, the level of the undesired signal can exceed the muting threshold of the victim receiver if the aircraft in the adjacent-channel service volume is near the victim. This could cause an undesirable on and off action of the squelch and possibly desensitize the victim receiver. To avoid this, the FAA separates adjacent-channel volumes by 2 nautical miles (4 kilometers).

The same level of performance must also be achieved when an odd 25-KHz (e.g., 118.075) channel is interleaved between 50-KHz channels (e.g., 118.050-118.100). The IF selectivity of a 50-KHz receiver will only provide 6 dB of rejection to a signal offset 25 KHz (see Figure 3).

FIGURE #3
REJECTION OF A 25KHz ADJACENT CHANNEL
BY THE IF SELECTIVITY OF A 50KHZ RECEIVER



This value was obtained assuming that both the victim receiver and interfering transmitter are at their maximum allowable frequency drifts; i.e., 0,003% for airborne equipment[3]. Thus, for the worst case situation, to provide the required 14 dB of interference protection, 8 dB (14 dB-6 dB) must be obtained as a result of geographic separation.

The need for a communication channel is defined as a requirement, and the fulfillment of that need with a frequency is an assignment. The demand for ATC channels is increasing as air traffic continues to grow. The result is that a shortage of interference-free air/ground assignments exists particularly in areas of high traffic density such as New York, Chicago, Los Angeles, and Atlanta.

The FAA has in the past assigned channels at 50-KHz tuning intervals in the VHF band; i.e., 118.050, 118.100, etc. To help satisfy the demand for ATC channels, the FAA has implemented a change to 25-KHz channel spacing; i.e., 118.050, 118.075, 118.100, etc. Because of the high capital investment by the civil aviation community in airborne equipment designed to operate with 50-KHz channel spacing, assignments of the odd 25-KHz channels have been made very selectively. This situation has created a mixed (interleaved) environment of 25-KHz and 50-KHz equipment. The combined effects of limited spectrum, the mixture of 25-KHz and 50-KHz equipment in the environment, the need to consider interference interactions caused by collocating many facilities, and the presence of FM and TV transmissions in adjacent bands have made the manual assignment of ATC frequencies more difficult and time-consuming than in the past.

PRODUCTS/EXPECTED RESULTS

Difficulty in accommodating new requirements using methods current at the time, was first noticed around 1970. An extensive manual study performed by the FAA and computer-assisted studies performed by the Electromagnetic Compatibility Analysis Center (ECAC), indicated that, without major changes in the way the ATC bands were utilized, the FAA would be unable to satisfy all of the anticipated future requirements. Changes considered included a redeployment of all existing assignments and channel splitting. Based on these studies, the FAA also determined that automated frequency assignment methods would be required to derived maximum benefit from any large-scale changes in the use of the VHF/UHF bands. In 1971, ECAC was contracted to develop an assignment model for the FAA that would incorporate the established FAA assignment criteria, include cosite interference calculations as well as high-power TV and FM considerations, and handle the mixed 25/50-KHz equipment environment.

As the development of this model progressed, the need for a second model was identified. The initial, more comprehensive, model was employed to explore methods of improving spectrum use. The purpose of the second model was to make available to frequency managers automated frequency assignment methods to more efficiently utilize the spectrum when making case-by-case frequency assignments. The initial model was first used in 1973. At that time, frequency-redeployment and channel-splitting proposals were investigated using the model. Major redeployment of frequencies proved to be impractical; however, the change to 25-KHz channel spacing was endorsed. The model was then used extensively to plan the first phase of the change to 25-KHz channel spacing. A UHF version of this model has also been developed for planning future FAA use of the ATC portion of the UHF band.

The second model, identified as the operational VHF model, was ready for use in 1977. This VHF model resides at ECAC and is available for use by FAA frequency managers. The frequency manager provides the name, location, and service volume of the requirement. This information is entered into the model, which produces a list of candidate frequencies for the frequency manager. The development of a comparable UHF operational model is possible, but at present has been delayed because of questions concerning the classified data files required for comprehensive cosite analyses. The VHF assignment model will reside at ECAC for at least another year in order to refine and evaluate the performance of the system. The FAA will then decide if this system should be implemented in their Regional Offices, either via commercial computer timesharing or via a remotely located minicomputer, thus eliminating the present verbal interference with ECAC. This operational VHF assignment model is the subject of this paper.

TECHNICAL APPROACH

Assignment Criteria. The term criteria applies to the standard values of parameters such as desired-to-undesired (D/U) signal ratio, geographic separations, and frequency separations, used in the frequency assignment evaluation procedure. In most cases, the assignment criteria used by ECAC in the

To calculate the D/U signal ratios in the cochannel and 25/50-KHz interleaving cases, two assumptions are made. First, that the effective isotropic radiated power (EIRP) of the desired signal is equal to the EIRP of the undesired signals. Secondly, that the propagation of the signal can be approximated by free-space loss within line-of-sight and by infinite loss beyond the radio horizon. The power budget shown in TABLE 1 reflects typical ground and airborne system parameters and illustrates the first assumption.

TABLE 1

POWER BUDGET

Parameter	Desired Signal (Ground)		Undesired Signal (Aircraft)	
Transmitter Output Power	10 watts	40.0 dBm	25 watts	44.0 dBm
Line Loss		-1.5 dB		-3.0 dB
Antenna		+2.2 dBi		+0.0 dBi
EIRP		40.7 dBm		41.0 dBm

The D/U ratio is calculated as follows:

$$D/U = EIRP_1 - L_1 - EIRP_2 + L_2 \qquad (1)$$

where:

D/U = the desired-to-undesired signal ratio, in dB

$EIRP_1$ = EIRP of the desired signal, in dBm

$EIRP_2$ = EIRP of the undesired signal, in dBm

L_1 = the transmission loss from the desired ground facility to the victim aircraft, in dB

L_2 = the transmission loss from the interfering aircraft to the victim aircraft, in dB

Since $EIRP_1$ is approximately equal to $EIRP_2$, equation (1) reduces to:

$$D/U = L_2 - L_1 \qquad (2)$$

Since it is assumed that L_1 and L_2 can be approximated by free-space loss, equation (2) becomes:

$$D/U = 37.8 + 20LOG_{10}\, d_u + 20LOG_{10} f - 37.8 - 20LOG_{10}\, d_D - 20LOG_{10} f \qquad (3)$$

where:

d_u = the distance between the victim and interfering aircraft, in nmi

d_D = the distance from the desired ground facility to the victim aircraft, in nmi

f = the frequency, in MHz

Equation (3) reduces to:

$$D/U - 20LOG_{10}\ (d_D/d_D) \qquad (4)$$

Equation (4) is used in the assignment model to determine D/U signal ratios. For a 14 dB D/U ratio, d_U must be approximately five times greater than d_D. This method of calculating D/U signal ratios closely approximates results obtained using median propagation curves for most cases of interest.

One of the more difficult compatibility problems involves the collocation of equipment. To assist with the solution to this problem, adjacent-signal frequency separations and intermodulation and harmonic protection calculations have been incorporated in the models. The standard FAA adjacent-signal separation for collocated facilities is 500 KHz. An 0.2 nmi (0.4 km) radius for the site allows for variations in the reported and recorded geographic coordinates of facilities actually at the same location. The intermodulation products considered in this model are two- and three-signal, third-order combinations of FM and TV broadcasting signals in the 54-108 MHz band and/or other aeronautical facilities in the 108-136 MHz band. These products are considered by the FAA to be the most harmful sources of interference to ATC ground facilities. Because of their high EIRP's, broadcasting stations as far away as 15 nmi (28 km) from the site can produce harmful intermodulation and harmonic products. Since aeronautical stations operate at much lower levels, only those frequencies assigned to aeronautical stations located within 2 nmi (4 km) of the site are considered in the analyses. These distances were judged to be large enough to include in the analyses the most likely potential sources of interference in the area without overly restricting the number of possible assignments. The model will not assign frequencies that would result in adjacent-signal, intermodulation, or harmonic interactions. Frequencies that would produce harmonic products in FAA UHF receivers in the area are also avoided. The 0.2, 2 and 15 nautical mile (0.4, 4 and 28 kilometer) criteria used for searching the data base were developed specifically for use in the assignment models.

Model Description. The objective was to develop a Remote Terminal Assignment Model that would utilize the FAA assignment criteria and perform the task in a timely manner. A responsive assignment model requires a data base that is structured to ensure fast access and efficient computational methods. Therefore, the model development was divided into two major tasks: 1) structure a data base and develop the necessary data management system to make the FAA-supplied data easily accessible to the model; and 2) develop an assignment capability that is consistent with the FAA-supplied criteria.

Data Base Design. Two types of data are required for FAA assignment model: data for the intersite analysis (requirement file), and data for the cosite analysis (background file).

The requirements file contains existing VHF assignments in the continental U.S., Canada, Mexico, and portions of the Caribbean. Each record contains the frequency, site name, site location, service-volume data (radius, altitude, service-volume center) and the unique requirement identification (ID) in the Government Master File (GMF). If the frequency serves an en route function (low-altitude or high-altitude), the latitude and longitude points that describe its multipoint service volume are also included in the record.

The second data file, the background file, contains those frequencies in the U.S. that are most likely to cause cosite problems for VHF assignments. Sources for this file are:

GMF: 108-136 MHz and 225-400 MHz bands

FCC: 54-108 MHz band

ARINC: 118-136 MHz band.

The background file is ordered by longitude, to permit rapid access to records for a specific geographic area. Each record in the background file contains the site latitude and longitude and the associated assigned frequency.

Assignment-Model Development. The assignment model must be able to perform data-base modifications and make the necessary cosite and intersite calculations. The initial assumption for any execution of the model is that all existing ATC requirements are currently satisfied. Any assignments to be made will result from new ATC requirements or requirements that need a frequency change. The model is divided into two sections: assignment problem definition, and assignment problem solution.

a. Assignment Problem Definition - The model provides the user with the ability to change the file to reflect the operating environment that will require new frequencies and/or frequency changes. Changes to the file are made by entering the unique GMF ID number, which enables the model to access the requirement that is to be modified or deleted. New requirements are entered by specifying the site name and location and all pertinent service volume information. The assignment process begins after all file changes have been entered.

b. Assignment Problem Solution - The process initiated by the user by specifying the cosite and intersite assignment criteria. The standard FAA criteria, discussed earlier, are preset in the model; however, the frequency manager has the flexibility to modify these criteria to account for unusual circumstances. Next, the user determines the frequency resources by specifying the channel spacing and frequency range or designating specific frequencies. Finally, the user specifies the requirement to be satisfied.

After all input data are specified, the model proceeds to the cosite and intersite analyses. To initiate the cosite analysis, frequencies are selected from the background file within a specified radius of the site where the frequency is to be assigned. The standard radius values are used; i.e., the 0.2; 2; and 15 nmi radii mentioned earlier. The model prohibits assignments that might contribute to such cosite interference phenomona as adjacent-signal, intermodulation, and harmonic interactions. The cosite analysis provides a list of all denied frequencies and the reason(s) for their denial. The intersite analysis begins by sequentially considering those candidate frequencies that have met the cosite criteria. These cosite-acceptable frequencies are tested to determine if they meet the cochannel and adjacent-channel criteria. Frequencies that meet the intersite criteria are shown to the user. The user may select the displayed frequency for assignment or continue to search for alternate acceptable frequencies. When a frequency is selected by the user, the model is instructed to record the assignment on a temporary basis and the user then designates the next requirement to be assigned a frequency. All frequencies assigned in a given execution of the model meet the FAA criteria and are compatible with the environment and other selections made during that execution. The data base reverts to its original configuration upon completion of the problem.

Sometimes, no frequency exists that meets all of the specified criteria. In this case, the user can return to the problem definition portion of the model to "free-up" a frequency. Frequencies can sometimes be made available to satisfy the new requirement by shifting the frequencies associated with one or two existing assignments. The file can handle 10 changes for any execution; therefore, the number of frequency shifts is limited. Frequencies for existing assignments so affected must be reassigned. Presently, the candidates for shifting are usually restricted to high en route facilities that can be reassigned on 25-KHz channels. (Only the high en route requirements utilize 25-KHz channels at present.) All other requirements are satisfied with 50 KHz channels.

Typical Examples. The FAA frequency managers have been using this model for over one year. In that time, over 100 operational frequency selections have been made with the model. In making these selections, the model has performed well and the results have been favorably received by the FAA Regional Frequency Managers.

The two examples below are typical of assignment problems that were solved by the model. The first example illustrates a problem in which an existing assignment had to be changed and the second example illustrates how an assignment for a new ATC requirement is determined.

Example 1 - A low en route assignment at Dayton, Ohio, presently using 134.450 MHz, was interfering with a high en route assignment at Brunswick, Georgia. The calculated D/U signal ratio was 10.1 dB. There was also an intermodulation problem on 134.450 MHz. No violation free 50-KHz channels were available, so the frequency of an existng assignment had to be changed to accommodate Dayton. One of the best candidate frequencies for Dayton was 127.850 MHz, because only one existing assignment (Portsmouth, Ohio) would need to be changed to permit Dayton to use 127.850 MHz. The assignment at Portsmouth was a high en route frequency that could switched to a 25-KHz channel. Therefore, Portsmouth was changed to 135.175 MHz and Dayton was assigned on 127.850 MHz.

Example 2 - A local control frequency assignment at Boise, Idaho, was needed to serve general aviation aircraft, many of which have vintage radios that tune only to channels spaced at 100-KHz intervals in the 118.0-126.9 MHz band. Initially, only two signal third order intermodulation protection was specified and three frequencies, 120.6, 120.7 and 125.9 MHz, passed all the criteria. It was later learned that the three-signal intermodulation protection was required which resulted in only 120.6 MHz meeting the criteria. Therefore, 120.6 was proposed for assignment at Boise.

SUMMARY

A frequency assignment model has been designed to help the FAA frequency managers make assignments that meet all of their prescribed assignment criteria. The model provides the user with a variety of capabilities not generally found in a single model, and offers a substantial savings in time, effort, and regional resources. Cosite calculations for any site in an urban area would normally take an engineer many hours to complete. The model performs the cosite analysis, including a search for the frequencies to be considered, in a matter of seconds. The model also gives the frequency managers the flexibility to define each assignment problem to reflect conditions of which only they might be aware, and this knowledge is often a very important ingredient in a go/no-go assignment situation.

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